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# Inverse color to black-and-white halftone conversion via dictionary learning and color mapping

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This paper challenges the problem of estimating the original red–green–blue (RGB) image from a black-and-white (B&W) halftone image with homogeneously distributed dot patterns. To achieve this goal, training RGB images are converted into color-embedded gray images using the conventional reversible color to gray conversion method, and then converted into halftone images using error diffusion in order to produce the corresponding B&W halftone images. The proposed method is composed of two processing steps: (1) restoring the color-embedded gray image from an input B&W halftone image using a sparse linear representation between the image patch pairs obtained from the images and (2) restoring the original colors from the color-embedded gray image using the reversible color to gray conversion and linear color mapping methods. The proposed method successfully demonstrates the recovery of colors similar to the originals. The experimental results indicate that the proposed method outperforms the conventional methods. It is suggested that our method is not only successfully applied for the color recovery of the B&W halftone image, but that it can also be extended to various applications including color restoration of printed image, hardcopy data hiding, and halftone color compression.



## 1. Introduction

Color is useful as a means of enhancing and emphasizing the visual information in digital images including pictures, illustrations, documents, presentation slides, etc. It is also an important factor influencing the visual attraction of such images. Colors are usually designed with graphics or office software programs, or they can be captured by digital imaging devices such as cameras or scanners. In most cases, each color is expressed as a three-dimensional (3D) vector whose elements contain 256 discrete levels, especially in the RGB color space [25]; however, color often needs to be converted to a gray scalar quantity for many purposes including black-and-white printing, data transmission via a mono fax, design of an algorithm in image processing and computer vision, and artistic rendering [42].

Since this color to gray conversion reduces the dimensionality, various colors can be mapped to the same gray; hence, the reverse color to gray conversion that estimates the original colors from the gray color in an image is an ill-posed problem. Even though a possible effective solution is the use of a new color transferring method [51] or colorization method [24,50] that assigns realistic pseudo colors to the grays according to the structure and object similarity between a reference color image and an input gray image, such methods are limited in recovering the unknown original colors due to unstable spatial

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and luminance matching between the two images. In addition, the same objects or species in an image may have different colors, and thus no reference color image that is perfectly matched to a unique gray image would be found. However, recently developed reversible color to gray conversion methods [9,29] have been successful in recovering the original colors from the gray image. These methods are based on color extraction from the embedded chrominance images stored in the high-frequency wavelet sub-bands. A relatively large amount of information (e.g., two resized chrominance images) can be encoded as pleasant and less visible texture patterns that are highly correlated with image contents. These reversible color to gray conversion methods have provided a breakthrough in original color estimation from a gray image.

Nevertheless, the more challenging problem remains in estimating the original colors from a B&W halftone image with homogeneous dot patterns [5], a type of image widely used in digital printers, copiers, and fax machines. This problem is generalized to finding the 3D vector with 256 discrete levels from a scalar quantity with two discrete levels per pixel position, and thus it is a highly ill-posed problem. In some applications, it is more important to recover the original colors from the B&W halftone image than from the gray image with 256 discrete levels. In B&W printing, digital halftoning [16,27] is conducted after the color to gray conversion to produce a B&W halftone image. The B&W halftone image is used to determine whether or not the black toner particles will touch the surface of the photoconductor drum in laser printers, whereas inkjet printers use it to determine the spatial position of the black ink drops on the paper. Regardless of the type of printed materials, such as printouts, newspapers or books, the printed images are binary images composed of homogeneous dot patterns. In the binary images, the printed areas with black toner or ink represent the logical value 1, and the unprinted areas represent the logical value 0. Even when a color image is converted into a B&W halftoned image in order to reduce consumption of expensive color inks or toners, recovery of the original colors is often required. In addition, the B&W halftone image transmitted via a monochromatic fax can be stored in the memory of the client's fax machine or multifunctional printer (MFP). In this case, it is very useful to directly recover the original colors from the B&W halftone image. This inverse color to B&W halftone conversion is widely applicable for practical purposes, including hardcopy data hiding and halftone image compression.

## 2. Background and motivation

Conventional color to gray conversion methods [3,18,19] have attempted to preserve salient chromatic structures, color edges, and contrast, thereby offering salient information. However, reversible processing has not been considered in previous studies. Reversible color to gray conversion algorithms have been developed in recent years [6,8,23,26,28,36]. A basic algorithm was introduced by de Queiroz and Braun [9] and involves smoothly mapping colors to high-frequency textures. The procedure of embedding the color information into a gray image is illustrated in Fig. 1. First, the RGB image is converted into the YCbCr image, and the discrete wavelet transform (DWT) is then applied to the Y image. To embed the color information (Cb and Cr images) in the gray image (Y image), the down-sampled Cb and Cr images are copied into the HL and LH subbands, respectively. The color-embedded gray image is finally obtained through the inverse discrete wavelet transform (IDWT). To verify how the embedded colors in the subbands are encoded in the gray image, the region marked with a red rectangle is magnified in the next row. Compared to the original gray patch extracted from the Y image, the embedded colors are encoded as less visible textures. This is possible due to the characteristics of the human visual system (HVS) that are insensitive to high frequencies [5,37]. However, since de Queiroz's method embeds the color information into HL and LH subbands, the textures tend to be vertical or horizontal lines. To reduce the texture visibility, Ko et al. [29] used a discrete wavelet packet transform (DWPT), providing more decomposed subbands. In their method, the color information is inserted into two subbands with a minimum amount of information, i.e., the horizontal subband of a vertical subband and the vertical subband of a horizontal subband. As shown in Fig. 1, the texture visibility can be significantly reduced by Ko's method. Despite the existence of other types of color-embedding methods [8,23,36], the goal of this paper is not to evaluate the performance of the methods and select the best one. Thus, one color-embedding method is sufficient to verify the effectiveness of the proposed method. The procedure for the color decoding method for extracting the original Cb and Cr images from the color-embedded gray image is in the inverse order of the color embedding method. A more detailed algorithm can be found in [9,29].

As mentioned earlier, the estimation of the original colors from the B&W halftone image, rather than the gray image, is required in some applications. In Fig. 1, if the color-embedded gray image is halftoned through digital halftoning, most textures indicating the color information, i.e., Cb and Cr images, will be destroyed, and a new original color estimation will therefore be needed from the B&W halftone image where color information loss has already occurred. Three B&W halftone images corresponding to the original gray image and two color-embedded gray images generated by de Queiroz's and Ko's methods are given in the third row of Fig. 1. The B&W halftone patterns corresponding to the color-embedded gray image with de Queiroz's method are not homogeneous due to the encoded vertical or horizontal textures. This contradicts the halftone design principle [5,16]. In addition, the horizontal and vertical line textures can be seen on the restored color images, which can degrade the visual quality. On the other hand, the B&W halftone patterns of the color-embedded gray image generated by Ko's method are similar to those of the original gray image due to the less visibly encoded textures. Therefore, it is preferable to use the homogeneously distributed halftone patterns for original color estimation. As shown in the third row of Fig. 1, the B&W halftone images are binary images with black and white dots, and thus estimating the original RGB image (3D vector) from the B&W halftone image (scalar quantity) is an ill-posed problem.