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Improving Reversible Color-to-grayscale Conversion with Halftoning

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Abstract: *Reversible color-to-grayscale conversion (RCGC) aims at embedding the chromatic information of a full color image into its grayscale version such that the original color image can be reconstructed in the future when necessary. Conventional RCGC algorithms tend to put their emphasis on the quality of the reconstructed color image, which makes the color-embedded grayscale image visually undesirable and suspicious. This paper presents a novel RCGC framework that emphasizes the quality of both the color-embedded grayscale image and the reconstructed color image simultaneously. Its superiority against other RCGC algorithms is mainly achieved by developing a color palette that fits into the application and exploiting error diffusion to shape the quantization noise to high frequency band. The improved quality of the color-embedded grayscale image makes the image appears as a normal image. It does not catch the attention of unauthorized people and hence the embedded chromatic information can be protected more securely.*

Keywords: *Reversible Color mapping, Information Hiding, Halftoning, Color Quantization, Color Palette, Noise Shaping*

1. Introduction

Color images are heavily and widely used nowadays in multimedia applications. In some applications, we allow the grayscale content of an image to open to the public but only disclose its color information to a group of privileged people (e.g. the private digital painting database of the Louvre Museum of Paris, France) [1-4]. Sometimes, due to some practical constraints, we are forced to deliver or present an image in grayscale temporarily but we need its color information in the future[5-8]. In either scenario, it would be desirable to convert a full color image into a grayscale image with the chromatic information embedded inside such that we can reverse the color-to-grayscale conversion afterwards to reconstruct a color image which is close to the original. A reversible color-to-grayscale conversion supports the reversion purposely.

When an image is delivered electronically, it is possible to extract the chrominance information from the image, encrypt it and then keep it as side information for future use. However, this approach may make the image not compatible with a conventional format. Since the chrominance information is not self-contained in the image, none of it can be recovered without the side information. Worst still, it makes the image file suspicious as non-privileged people can easily find some mysterious data not interpretable, which is not acceptable when we do not want to trigger any unbearable or unpredictable consequences. In contrast, if the chrominance information is directly embedded in the grayscale image itself, the aforementioned problems can be automatically solved.

The basic idea of reversible color-to-grayscale conversion (RCGC) is to embed the chromatic information of a color image in its grayscale version. Since it involves information embedding, a naive approach is to compress the chromatic information and then embed it as binary data into the grayscale version with a reversible data hiding algorithm such as [9-11]. However, this approach does not provide a good performance in practical situations because the color information of a natural image increases with the image size and it is too rich for a reversible data hiding algorithm to handle. For example, even after a 4:2:0 chrominance subsampling process [12] is performed, the average entropy of the chrominance content of the color images in the Kodak set [13] is 2.9 bits per pixel (bpp), which still significantly exceeds the capacity of state-of-art reversible data hiding algorithms, and hence a further compression is required. The chromatic quality of the reconstructed color image can be degraded remarkably at a high compression ratio. Dedicated RCGC algorithms are hence needed to address this specific issue.

State-of-art RCGC algorithms are either based on vector quantization (VQ) technique [1-4,14] or subband embedding (SE) technique [5-8,15-17]. A VQ-based algorithm generates a palette of 256 colors with a clustering algorithm such as [18,19], quantizes each pixel color of the color image to one of the palette colors, and then uses the