Signal Processing 98 (2014) 295–307

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

Fast image enhancement in compressed wavelet domain ☆

Dongwook Cho *, Tien D. Bui

Department of Computer Science and Software Engineering, Concordia University, 1455 De Maisonneuve Blvd. West, Montréal, Québec, Canada H3G 1M8

ARTICLE INFO

Article history:
Received 24 March 2013
Received in revised form
2 November 2013
Accepted 7 November 2013
Available online 16 November 2013

Keywords:
Image enhancement
Contrast enhancement
Wavelet transform
JPEG 2000
Denoising

ABSTRACT

This paper presents computationally efficient framework for color image enhancement in the compressed wavelet domain. The proposed approach is capable of enhancing both global and local contrast and brightness as well as preserving color consistency. The framework does not require inverse transform for image enhancement since linear scale factors are directly applied to both scaling and wavelet coefficients in the compressed domain, which results in high computational efficiency. Also contaminated noise in the image can be efficiently reduced by introducing wavelet shrinkage terms adaptively in different scales. The proposed method is able to enhance a wavelet-coded image computationally efficiently with high image quality and less noise or other artifacts. The experimental results show that the proposed method produces encouraging results both visually and numerically compared to some existing approaches.

1. Introduction

Natural images can be degraded when they are acquired due to lighting condition, sensor resolution and quality, or limitation or noise of optical system. In addition, most of natural images are compressed with a certain degree of data loss for more efficient storage and communication. An image enhancement algorithm makes such degraded images visually better perceived. It is a fundamental problem in image processing field and somehow subjective since the quality is decided by human visual system (HVS). The enhanced image is expected to have better brightness and contrast, good color consistency, reduced noise or defect, less visual artifacts, or better resolution. Depending on the quality of a given degraded image, each of these improvement factors has become an important topic separately in areas such as denoising, contrast enhancement, white balance, deblurring, demosaicking, deblocking, super-resolution, inpainting. Among them, comfortable brightness, contrast, and color consistency are major enhancement factors to HVS since photoreceptors in retina (rod and cones) are mainly stimulated differently by light strength levels and wavelengths, and transduce different levels of stimuli to send the analyzed signal to the brain. In this paper, the image contrast, brightness, color consistency, and level of noise are considered as major enhancement factors.

There have been various works along this line. In the spatial domain, there have been many good methods that can be easily found in introductory image processing books.

Retinex-based approaches, one of the successful methods, express HVS adaptive dynamic ranges with different lighting conditions in the spatial domain [11,12,17]. Some efficient image enhancement approaches for the compressed discrete cosine transform (DCT) domain have been recently proposed in [14,19]. Since they can be applied directly to the encoded data, it is not required to decode the image for image enhancement. These methods also consider the degradation caused by the compression approach such as blocking artifact or related noise.

☆ This paper is an improved extension of the preliminary work presented in ICIP 2011 [7].

* Corresponding author.
E-mail addresses: luppos@gmail.com (D. Cho), bui@cse.concordia.ca (T.D. Bui).

0165-1684/$ - see front matter Crown Copyright © 2013 Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.sigpro.2013.11.007

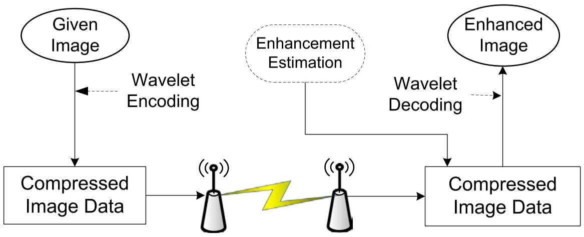

Fig. 1. Transmission of image data.

Wavelet transforms have been used for image contrast enhancement to take advantage of the multi-scale properties in the wavelet domain [24]. Curvelet is also used to preserve better the multi-scale edges [22]. The method proposed in [5] automatically chooses one discrete wavelet filter that can produce the best enhancement result for a given image. These methods are designed to use wavelet transforms to achieve a better image enhancement quality. Therefore, computational efficiency regarding transformation or data transmission was not considered. On the other hand, our method puts an emphasis on the image data processing in the wavelet compressed domain itself. Fig. 1 shows a conceptual diagram for the communication process of compressed image data. In the process, image enhancement can be implemented directly in the compressed domain.

In this paper, we propose a new, fast image enhancement framework in the compressed wavelet domain, especially for JPEG 2000. The framework is required to estimate the enhanced transformed image data by applying scale factors of scaling and wavelet coefficients. Since each meaningful wavelet coefficient is simply scaled by a proposed formulation, the framework is computationally efficient. In addition, the framework is flexible since the resulting scaling factor for wavelet coefficients is a combination of global scaling enhancement factor for a scaling coefficient, shrinkage factor for noise suppression, and wavelet enhancement factor. We derive the scaling factors by taking into account the multi-scale property and the low- and high-pass representation of the wavelet transforms.

The paper is organized as follows. In the following section, we briefly review the discrete wavelet transform and its properties for image enhancement problem. Proposed algorithm is described in Section 3. Then experimental results and performance evaluation are demonstrated before concluding this work.

2. Brief wavelet theory

Wavelet transform has been used for better quality compression due to its efficient separability into dense scaling coefficients and sparse wavelet coefficients. JPEG 2000 is a representative standard which can replace the DCT-based JPEG. In JPEG 2000, symmetric filters with biorthogonal property such as Le Gall 5/3 and CDF 9/7 have been chosen. Unlike orthonormal wavelet filters with some nice mathematical properties, biorthogonal wavelet causes a difference between the scaling and wavelet filters in their filter lengths; However, biorthogonal wavelet makes it possible for simple and fast implementation. In this section, basic notions and mathematical properties for wavelet-based image enhancement approaches used in this paper are briefly described. More details on wavelet theory or JPEG 2000 standard can be found in various papers including [10,15,21,23]. The one-dimensional forward discrete wavelet transform can be expressed as follows:

$$s_{j+1,k} = \sum_{m=-\lfloor (p-1)/2 \rfloor}^{\lfloor p/2 \rfloor} \phi_m s_{j,2k-m} \tag{1}$$

$$w_{j+1,k} = \sum_{m=-\lfloor (q-1)/2 \rfloor}^{\lfloor q/2 \rfloor} \psi_m s_{j,2k-m+1}, \tag{2}$$

where $s_{j,k}$ and $w_{j,k}$ are scaling and wavelet coefficients in j-th level and ϕ_m and ψ_m are the scaling and wavelet filters with length p and q respectively. Also, $\sum \phi_m = \sqrt{2}$ and $\sum \psi_m = 0$. For instance, the forward transform by Le Gall 5/3 filter can be defined as

$$s_{j+1,k} = \sqrt{2}\left[\tfrac{3}{4} s_{j,2k} + \tfrac{1}{4}\left(s_{j,2k-1} + s_{j,2k+1}\right) - \tfrac{1}{8}\left(s_{j,2k-2} + s_{j,2k+2}\right)\right] \tag{3}$$

$$w_{j+1,k} = \tfrac{1}{\sqrt{2}}\left[s_{j,2k+1} - \tfrac{1}{2}\left(s_{j,2k} + s_{j,2k+2}\right)\right]. \tag{4}$$

The inverse wavelet transform for synthesis can be expressed as follows:

$$s_{j,k} = \frac{1}{2}\left[\sum_{m=-\lfloor (p-1)/2 \rfloor}^{\lfloor p/2 \rfloor} \check{\psi}_m s_{j+1,k-m} + \sum_{m=-\lfloor (q-1)/2 \rfloor}^{\lfloor q/2 \rfloor} \check{\phi}_m w_{j+1,k-m}\right], \tag{5}$$

where $\check{\psi}_m$ and $\check{\phi}_m$ are the synthesis filters of the scaling and wavelet functions and the coefficients s_{j+1}, k and w_{j+1}, k are upsampled. In the case of Le Gall 5/3 using Eq. (5), even and odd sampled scaling coefficients in the j-th level are obtained by

$$s_{j,2k} = \tfrac{1}{\sqrt{2}}\left[s_{j+1,k} - \tfrac{1}{2}\left(w_{j,k-1} + w_{j,k}\right)\right] \tag{6}$$

$$s_{j,2k+1} = \sqrt{2}\left[\tfrac{3}{4} w_{j,k} + \tfrac{1}{4}\left(s_{j,k} + s_{j,k+1}\right) - \tfrac{1}{8}\left(w_{j,k-1} + w_{j,k+1}\right)\right]. \tag{7}$$

The shapes of the analysis and synthesis filters for Le Gall 5/3 are illustrated in Fig. 2.

In 2D wavelet transform, j-th level scaling coefficients are located in LL_j subband while wavelet coefficients are separated into HL_j, LH_j, and HH_j subbands. The 2D implementation can be made straightforward by applying 1D transform to rows and then columns of the image or the scaling subband in the previous decomposition level.

3. Proposed wavelet framework for image enhancement

The proposed framework enhances an image in the wavelet transform domain that produces scaling and wavelet coefficients. Therefore, it is essential to estimate appropriate scaling and wavelet coefficients. We propose a fast and efficient image enhancement framework that uses fast scale factors with a flexible mapping criteria. The estimation of scale factors for scaling coefficients is proposed in Section 3.1. and for wavelet coefficients in Section 3.2.