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Color image detail enhancement based on quaternion guided filter

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Abstract

Color image enhancement is an active research field in image processing. Currently, many image enhancement methods are capable of enhancing the details of the color image. However, these methods only process the red, green and blue (RGB) color channels separately, which leads to color distortion easily. In order to overcome this problem, the paper presents an approach to integrate the quaternion theory into the traditional guided filter to obtain a quaternion guided filter (QGF). This method makes full use of the color information of an image to realize the holistic processing of RGB color channels. So as to preserve color information while enhancing details, this paper proposes a color image detail enhancement algorithm based on the QGF. Experimental results show that the proposed algorithm is effective in the applications of the color image detail enhancement, and enables image's edges to be more prominent and texture clearer while avoiding color distortion. Compared with the existing image enhancement methods, the proposed method achieves better enhancement performance in terms of the visual quality and the objective evaluating indicators.

Keywords detail enhancement, quaternion guided filter, self-adaptive enhancement transform

1 Introduction

As a useful information carrier, the image is a source to obtain and exchange information. Most information of human is acquired by vision. Therefore, image processing plays an important role on human's life and work. At present, digital image processing has performed very well in a great variety of fields such as medical engineering, atmospheric sciences, military reconnaissance and computer vision, etc. Image enhancement is an image pre-processing stage which plays an increasing role in the whole image processing. It is adopted to make details prominent, remove noises, improve the quality of the image and make images more suitable for human visual perception. In recent years, image enhancement technology has gradually become a vital domain of the image processing and drew a wide of attentions. Many completive image enhancement algorithms have been provided, which mainly can be classified as two key areas: spatial domain processing and transform domain processing. The spatial domain methods directly operate on the pixels of an image, and most representatives of those methods are based on histogram equalization (HE) [1–2], contrast stretching [3–4], and fashionable Retinex algorithms [5–7]. The transform domain methods process the frequency information of the image, such as the Fourier, wavelet [8], curvelet [9] and contourlet [10–11]. Many kinds of filters have been proposed, such as the anisotropic filter [12] and the bilateral filter [13–15], which are aiming at smoothing image details while preserving the sharpness of salient edges [16–17]. These edge-aware filtering methods have been applied into the detail enhancement of an high dynamic range (HDR) image [15], style transfer [18] and haze removal [19–20]. And Yan et al. [21] presented a machine-learned approach for automatically enhancing the color of an image, which takes into account the intermediate decisions of a human user in the color editing process. Although most of image enhancement methods can improve the visual effects of the degraded images to some degree, they still suffer from some

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inherent defects, such as gradient reversal, halos and color distortion. For example, the bilateral filter has been suffering from gradient reversal artifacts [22]. The reason is that when a pixel (often on an edge) has few similar pixels around it, the Gaussian weighted average is unstable. Edge-preserving and detail-smoothing often are treated as contradictory procedures. The perfect edge-preserving filter must neither blur nor sharpen the edges while smoothing the detail regions between such edges. In fact, it is difficult to achieve an optimal trade-off between blurring and sharpening edges, as it is generally impossible to explicitly point out which edges should be preserved.

Although great achievements have been gained in the enhancement of grayscale images, some algorithms fail to yield the desired processing results of color images. Gradient reversal, halos, color distortion and over-sharpening may happen and affect the visual quality of color images. Most algorithms do not exploit the correlations between the different channels and process the RGB color channels separately, which may change image color mechanism and leave out some information that may affect the results of image enhancement.

Due to the above problems, this paper introduces the concept of quaternion [23] into the color image enhancement theory and combines quaternion with guided filter, and the QGF is constructed. Guided filter does not only have the edge-preserving smoothing property like the bilateral filter, but also perform better than avoiding the gradient reversal artifacts in image detail enhancement due to the abrupt change of the edge. The QGF encodes three color components of the image as a pure quaternion, and treats them as an entity to keep color information of images.

In this paper, a color image enhancement algorithm based on the QGF is proposed. With QGF, the operation is based on a two-scale decomposition of the image, and it is divided into a base layer and a detail layer. Linear detail enhancement is utilized to enhance the detail layer globally and saliency enhancement can make salient regions more clear, a weighting combination guided by a simplified saliency map is employed to blend the two enhancement results. The saliency feature extraction [24] applies different weights to each pixel, and extracts the target regions which have plentiful details, thus greatly improves the visual quality of enhancement results. With the extracted saliency map, the saliency enhancement makes interesting regions salient. Different emphasis is applied on detailed and smooth regions guided by image content saliency. The enhancement results are blended being weighted by a saliency map. The enhancement approach can effectively produce high quality detail enhancement and edge-preserving smoothing based on suitable color spaces, while avoiding halo artifacts, loss of details and over-enhancement. Experimental results show that the proposed method is promising, and it does significantly improve the visual quality of the color image compared to the existing enhancement methods.

The rest of the paper is structured as follows. Sect. 2 firstly gives a brief introduction of quaternion, and then QGF is introduced. Sect. 3 illustrates the color image enhancement algorithm based on QGF. In addition, the performance of the proposed enhancement method is evaluated via some experiments in Sect. 4, and the subjective and objective comparisons with the existing methods are discussed. Finally, conclusions are made in Sect. 5.

2 Definition

2.1 Quaternion

The concept of quaternion, non-commutative extension of the complex domain, was introduced by Hamilton [23]. Since 1985, the quaternion has been used more and more in modern signal processing domain. At first, the quaternion had no direct connection with color images. After Pei et al. found that the data structure has a corresponding relationship [25–26] with the pixels of the color image, quaternion has been utilized increasingly in color image processing domain. The quaternion q has a real part and three imaginary parts and can be written as:

$$q = q_{\mathrm{r}} + \mathrm{i}q_{\mathrm{i}} + \mathrm{j}q_{\mathrm{j}} + \mathrm{k}q_{\mathrm{k}} \tag{1}$$

where q_{r} is the real part and q_{i}, q_{j}, q_{k} are the three imaginary parts, i, j, k are complex operators obeying the following rules:

$$\mathrm{i}^2 = \mathrm{j}^2 = \mathrm{k}^2 = \mathrm{ijk} = -1 \tag{2}$$

$$\left.\begin{aligned} \mathrm{ij} &= -\mathrm{ji} = \mathrm{k} \\ \mathrm{jk} &= -s = \mathrm{i} \\ \mathrm{ki} &= -\mathrm{ik} = \mathrm{j} \end{aligned}\right\} \tag{3}$$

If q has a unit norm ($\|q\| = 1$), we call q unit quaternion, and if the real part of q is zero ($q_{\mathrm{r}} = 0$), then we call q pure quaternion. The modulus and conjugate of quaternion q are defined respectively as follows: