J. Vis. Commun. Image R. 19 (2008) 299–310

Contents lists available at ScienceDirect

J. Vis. Commun. Image R.

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

Efficient edge-preserving algorithm for color contrast enhancement with application to color image segmentation

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ARTICLE INFO

Article history:
Received 17 July 2006
Accepted 22 February 2008
Available online 13 March 2008

Keywords:
CIE color model
Color contrast enhancement
Color edge detection
Color histogram moment
Color image segmentation
Color saturation and desaturation
Edge-preservation effect
Seed-based region growing approach

ABSTRACT

In this paper, a new and efficient edge-preserving algorithm is presented for color contrast enhancement in CIE Lu′v′ color space. The proposed algorithm not only can enhance the color contrast as the previous algorithm does, but also has an edge-preservation effect. In addition, the spurious edge points occurred due to the color contrast enhancement can be well reduced using the proposed algorithm. This is the first edge-preserving algorithm for color contrast enhancement in color space. Furthermore, a novel color image segmentation algorithm is presented to justify the edge-preservation benefit of the proposed color contrast enhancement algorithm. Based on some real images, experimental results demonstrate the advantages of color contrast enhancement, edge-preservation effect, and segmentation result in our proposed algorithm.

1. Introduction

The purpose of color contrast enhancement is to enhance a color image such that the enhanced color image is more colorful than the original color image from the viewpoint of human visual system [8,21,22]. Previously, many efficient algorithms for color contrast enhancement have been successfully developed. Based on reducing color ordering approach [2], Zaharescu et al. [31] presented a color contrast enhancement algorithm. Based on the curvelet transform approach [4,26], Starck et al. [25] presented an efficient algorithm for color contrast enhancement. Recently, a two-step approach, namely the saturation step and the desaturation step, was proposed for color contrast enhancement [13,20]. In Lucchese et al.'s algorithm [13], they considered the chromaticity diagram [11,14]. In Pei et al.'s algorithm [20], the considered color domain is the modified chromaticity diagram, i.e. the CIE Lu′v′ color space [11]. In [20], Pei et al. also developed some efficient methods to the restoration of Chinese paintings.

Among these previously published color contrast enhancement algorithms, although the enhanced color image has good color contrast enhancement effect, some degree of edge-loss may happen. Due to the edge-loss side effect, some further color image processing tasks, such as color image segmentation and object recognition, may be degraded. The main motivations of this research are twofold: (1) presenting a new algorithm to come to a compromise between the edge-preservation effect and the color contrast enhancement effect and (2) presenting a novel color image segmentation algorithm to justify the edge-preservation benefit in some application.

In this paper, a new edge-preserving algorithm for color contrast enhancement is presented. Our proposed algorithm has both advantages of edge-preservation effect and color contrast enhancement. Our proposed algorithm consists of three steps: in the first step, a saturation operation is performed to maximize the color contrast effect. In order to speed up the first step, a new history-aid strategy is presented to determine the most possible side of the color gamut triangle in the CIE Lu′v′ color space. In the second step, a desaturation operation is performed to enrich the colorful degree. The above two steps are similar to the previous color contrast enhancement algorithms in [13,20]. In the third step, an edge-preservation operation is performed to preserve the edge information while keeping the color contrast enhancement effect as much as possible. In addition, the spurious edge points occurred due to the color contrast enhancement can be well reduced using the proposed algorithm. Some experiments are carried out to demonstrate that our proposed algorithm has a good compromise between the edge-preservation effect and the color contrast enhancement. This is the first edge-preserving algorithm for color contrast enhancement in color space. Finally, a novel color image segmentation algorithm is presented to justify the application of edge-preservation effect. In our proposed color image segmentation algorithm,

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[1] Supported by the National Science Council of ROC under Contracts NSC96-2221-E-011-102-MY3, NSC96-2221-E-011-026, and NSC96-2219-E-001-001.

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doi:10.1016/j.jvcir.2008.02.002

we have better segmentation results on our obtained enhanced image when compared to those on the previous obtained enhanced image without edge-preservation.

The remainder of this paper is organized as follows: in Section 2, first the notion of CIE Lu′v′ color space is introduced and then the previous color edge detector, which will be used in our proposed color contrast enhancement algorithm, is described. In Section 3, our proposed edge-preserving algorithm for color contrast enhancement and the relevant speedup strategy are presented. In Section 4, a novel color image segmentation algorithm is presented. In Section 5, some experimental results are carried out to demonstrate advantages of color contrast enhancement, edge-preservation effect, and segmentation result in our proposed algorithm. Finally, some conclusions are addressed in Section 6.

2. Preliminaries

Before presenting our proposed color contrast enhancement algorithm, this section introduces two backgrounds, namely the notion of CIE Lu′v′ color space [11] and the previously published color edge detector by Trahanias and Venetsanopoulos [29]. The two backgrounds will be used in Section 3.

2.1. The CIE Lu′v′ color space

Suppose the input color image is an RGB color image. First, the transformation from the RGB color space to the CIE Lu′v′ color space is described. The relevant transformation can be expressed by

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.49000 & 0.31000 & 0.20000 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00000 & 0.01000 & 0.99000 \end{bmatrix} \begin{bmatrix} \mathrm{R} \\ \mathrm{G} \\ \mathrm{B} \end{bmatrix} \quad (1)$$

In Eq. (1), the component Y is the L component in the CIE Lu′v′ color space. Therefore, the CIE Lu′v′ color space can be called the CIE Yu′v′ color space. Based on the values of X, Y, and Z, the two components u' and v' can be obtained by the following equation:

$$u' = \frac{4X}{X + 15Y + 3Z}, \quad v' = \frac{9Y}{X + 15Y + 3Z} \quad (2)$$

By Eqs. (1) and (2), the RGB color space can be transformed into the CIE Lu′v′ color space.

Considering only the two components u' and v', Fig. 1 depicts the so called spectral locus of the $u'v'$ chromatic diagram and the spectral locus is depicted by the exterior curve. Within the spectral locus, the triangle area denotes the color space which can be displayed by the CRT monitor. This triangle area is commonly called the color gamut triangle. The three corners of the color gamut triangle are denoted by the three points R′, G′, and B′ which are corresponding to $(u'_{R'}, v'_{R'}) = (0.4507, 0.5229)$, $(u'_{G'}, v'_{G'}) = (0.1250, 0.5625)$, and $(u'_{B'}, v'_{B'}) = (0.1754, 0.1579)$. The interior point $W = (u'_W, v'_W) = (0.1978, 0.4683)$ is defined as the white point [11]. Since the colors lain around the white point W are regarded as achromatic colors, it is infeasible to enhance these colors which are very near to the point W.

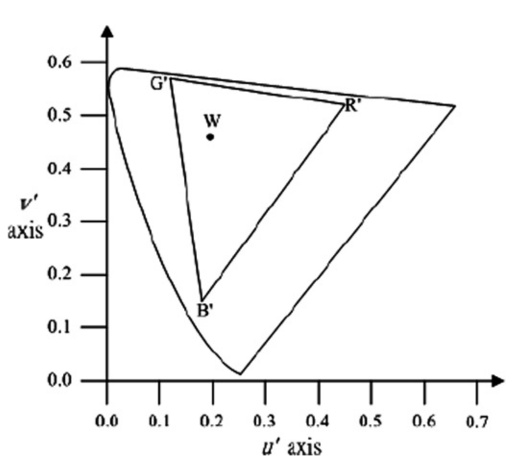

Fig. 1. The CIE $u'v'$ chromatic diagram.

2.2. Color edge detector

In this subsection, the color edge detector by Trahanias and Venetsanopoulos [29] is described and it will be used in our proposed edge-preserving algorithm for color contrast enhancement although some other color edge detectors [23,28,32] can also be considered.

Suppose the window mask used in the color edge detector is of size $w \times w$ and the w^2 color pixels covered by the window mask are denoted by the set $P = \{P_1, P_2, \ldots, P_{w^2}\}$. Usually, w is selected to 3 or 5. The color contrast or difference expressed in the CIE Lu′v′ color space is more fruitful than that in the RGB color space [11]. Thus, instead of measuring the color difference in RGB color space, we estimate the color difference in the CIE Lu′v′ color space. The three color components of each color pixel are denoted by $P_i = (u'_i, v'_i, Y_i)$.

Based on the vector order statistic and the R-ordering concept [3], the color edge detector [29] consists of the following three steps:

Step 1: Sum up the color distances between each color pixel P_i and the other color pixels covered by the window mask. For color pixel P_i, $1 \leqslant i \leqslant w^2$, the resulting distance is given by $d_i = \sum_{k=1}^{w^2} \|P_i - P_k\|, i = 1, 2, \ldots, w^2$, where $\|\cdot\|$ represents an appropriate vector norm.

Step 2: Sort these w^2 distances $d_1, d_2, \ldots,$ and d_{w^2}. Suppose these sorted w^2 ascending distances are $d_{i(1)}, d_{i(2)}, \ldots,$ and $d_{i(w^2)}$ for $1 \leqslant i(1), i(2), \ldots, i(w^2) \leqslant w^2$. Among these w^2 indices, $P_{i(1)}$ is the color pixel with the minimal distance $d_{i(1)}$; $P_{i(w^2)}$ sometimes can be viewed as the outlier pixel in the w^2 color pixels.

Step 3: Based on the robustness consideration, compute the minimum vector dispersion (MVD) which is given by

$$\mathrm{MVD} = \min_j \left\{ \left\| P_{i(w^2-j+1)} - \sum_{m=1}^{n} \frac{P_{i(m)}}{n} \right\| \right\}, \quad j = 1, 2, \ldots, k; \; k, n < w^2.$$

In [29], k and n are selected to 3 or 4 empirically. When the value of MVD is greater than the specified threshold, the central pixel of the concerned $w \times w$ subimage is determined to be an edge pixel; otherwise, it is determined to be a non-edge pixel.

3. The proposed edge-preserving algorithm for color contrast enhancement

This section presents our proposed novel algorithm which can come to a compromise between the edge-preservation (including spurious edge-reduction) consideration and the color contrast enhancement. In what follows, we first describe the main concepts used in our proposed algorithm, and then a speedup strategy is given to improve the proposed algorithm.

3.1. The main concept

As mentioned above, our proposed edge-preservation algorithm for color contrast enhancement has two considerations, namely: (1) keeping the edge information after enhancing the color image