J. Vis. Commun. Image R. 39 (2016) 58–64

Contents lists available at ScienceDirect

J. Vis. Commun. Image R.

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

# 3-D color histogram equalization by principal component analysis

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ARTICLE INFO

*Article history:*
Received 29 August 2015
Revised 5 May 2016
Accepted 5 May 2016
Available online 10 May 2016

*Keywords:*
Color images
Image enhancement
Histogram equalization
Principal component analysis

ABSTRACT

Color histogram equalization is a method for improving visual appearance of images by enhancing image contrast. Color histogram equalization methods are mostly faced with problems like over-enhancement and brightening. In this paper a new color histogram equalization method is proposed which defines a new three dimensional cumulative distribution function based on a one-dimensional histogram. This one-dimensional histogram is calculated by taking into account the correlation between color channels using PCA. Over-enhancement and brightening are solved by this method because of applying the equalization on a transformed image instead of image itself.



## 1. Introduction

Image enhancement techniques modify images to improve the quality for human viewing or accuracy of image analysis tasks. Most image enhancement techniques are initially developed for gray scale images and then extended to color images. The extension is proven to be complicated due to the correlation between the color components.

Grayscale histogram equalization [1] is one of the simplest and most effective techniques for image enhancement. It is a transformation on image which modifies its intensity probability distribution function to be uniform and so enhances image contrast. Several attempts have been made for extending this technique to color images. These efforts can be divided into two main classes. The first class consists of methods which work on RGB space. Methods which operate in nonlinear spaces for example HSI or C-Y color spaces form the second class.

One of the most famous approaches of the first class is 3-D histogram equalization [2] proposed by Trahanias and Venetsanopoulos. They proposed a 3-D cumulative distribution function (CDF) for bringing into account the correlation between R, G and B components. The 3-D CDF of the original and uniform images are compared and the new RGB vector of each pixel is calculated based on this comparison. This method is further explained in Section 2.1. 2-D histogram equalization [3] is another method of the first class. This method uses three 2-D histograms instead of one 3-D histogram. It uses the correlation of color channels two at two. This method is explained further in Section 2.2. Another significant method is "iso-Luminance Plane" method [4] proposed by Han et al. Regardless of the correlation between channels, this method calculates an intensity value for each pixel based on the values of R, G and B.

There are several other equalization techniques in the RGB space. For example histogram explosion [5], histogram decimation [6], mesh deformation [7] and many other methods [8–10] which are not related directly to the work of this paper. This paper is focusing on the first class; therefore some dominant methods of this class are discussed in Section 2. It is worth mentioning that in the other class, histogram explosion [11] is an equalization technique which works on the CIELUV color space. It equalizes a one dimensional histogram constructed by interpolation. In [12] another technique is introduced which works on the CIE space and equalizes the achromatic channel in this space. Proposed method of paper [13] which equalizes the saturation component within various ranges of the hue and intensity, works on the C-Y space. Some other techniques like [14–16] work on the HSI space by equalizing the intensity or joint equalization of intensity and saturation.

As mentioned earlier, 3-D histogram equalization suffers from over-enhancement. 2-D histogram equalization does not work well on the low correlation images and produces some artifacts [4]. Han et al. in [4] try to reduce these faults but ignore the correlation between R, G and B channels. Despite its satisfactory results in many cases, their proposed method still suffers from over-enhancement, because of ignoring the correlation and big changes in the brightness. In this paper a method is introduced which tries to overcome these problems using Principal Component analysis

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http://dx.doi.org/10.1016/j.jvcir.2016.05.002

(PCA) to decorrelate color components. PCA is used to project the subject image to a new space of uncorrelated components which are linear combinations of color components. Projection coefficients differ from one image to another depending on how correlated the image's color components are. The values of pixels projected on the first component of the new space which bears the most variability of data ignoring noises are used for histogram equalization. So the proposed method is a three-dimensional histogram equalization which applies equalization on a one-dimensional histogram of the PCA transformation of the original image. We expect the proposed method to overcome the over-enhancement problem while maintaining the advantages of the other methods.

## 2. Histogram equalization

### 2.1. Grayscale histogram equalization

As mentioned earlier, color image histogram equalization methods are extensions of grayscale histogram equalization (GHE). Histogram of a grayscale image $I$ denoted by $H^I$ consists of $H^I_{l_i}$ values where $H^I_{l_i}$ is the frequency of the intensity level $l_i$, $0 < l_i < L$ and $L$ is the number of intensity levels. Let $P^I$ be the probability density function (PDF) of the gray scale image $I$ i.e. $P^I_{l_i} = \frac{H^I_{l_i}}{n}$ and $n$ is the numbers of pixels in image $I$. Let $C^I_{l_i}$ be the CDF of the image $I$ i.e.

$$C^I_{l_i} = \sum_{l=0}^{l_i} P^I_l \tag{1}$$

After equalization the intensity of every pixel $l_i$ is transformed to $l'_i$ as follows:

$$l'_i = C^I_{l_i} = \sum_{l=0}^{l_i} P^I_l \tag{2}$$

One of the first proposed methods for color histogram equalization is applying GHE on each RGB channel separately. This method because of ignoring the correlation of the color channels and changing them separately is not hue preserving.

### 2.2. Three-dimensional histogram equalization

The method proposed by Trahanias and Venetsanopoulos for taking into account the correlation between $R$, $G$ and $B$ components defines a 3-D CDF as follows:

$$C^I_{R_i,G_i,B_i} = \sum_{r_i=0}^{R_i}\sum_{g_i=0}^{G_i}\sum_{b_i=0}^{B_i} P^I_{r_i,g_i,b_i} \tag{3}$$

Let $P^O_{R_O,G_O,B_O}$ be the uniform PDF of output image, i.e. $P^O_{R_O,G_O,B_O} = \frac{1}{L^3}$ for each $(R_O, G_O, B_O)$ vector. Therefore $C^O_{R_O,G_O,B_O}$ for each vector $(R_O, G_O, B_O)$ can be computed as follows:

$$C^O_{R_O,G_O,B_O} = \frac{(R_O+1)(G_O+1)(B_O+1)}{L^3} \tag{4}$$

For calculating the transformed value of each input pixel the smallest $(R_O, G_O, B_O)$ that satisfies the equation below is found in a hue preserving approach [2].

$$C^I_{R_i,G_i,B_i} = C^O_{R_O,G_O,B_O} \tag{5}$$

### 2.3. Two-dimensional histogram equalization

Menotti et al., instead of using the correlation between three channels as [2] use the correlation of them two at two i.e. $(R, G)$, $(R, B)$ and $(G, B)$. The CDF is defined for each pair. For example, the CDF of $(R, G)$ is defined as follows:

$$C^I_{R_i,G_i} = \sum_{r_i=0}^{R_i}\sum_{g_i=0}^{G_i} p^I_{r_i,g_i} \tag{6}$$

$C^I_{R_i,B_i}$ and $C^I_{G_i,B_i}$ can be computed similarly. CDF of the three components is computed by these three CDFs as follows and transformed values are calculated like the previous method.

$$C^I_{R_i,G_i,B_i} = C^I_{R_i,G_i} \times C^I_{R_i,B_i} \times C^I_{G_i,B_i} \tag{7}$$

As mentioned earlier the correlation between R, G and B channels is the main problem of extending GHE to color images. The method of [2] takes this correlation into account in the equalization process but this method suffers very seriously from over-enhancement [2,4]. Concentration of the bright pixels in the equalized image resulted from this method is higher than the original image. Menotti et al. try to solve this problem with a heuristic method in [3], but it suffers from unsatisfactory artifacts especially on low correlation images [4]. Han et al. present a new method of 3-D equalization to improving these methods.

### 2.4. Iso-luminance plane method

This method introduces a new CDF as follows:

$$C^I_{R_i,G_i,B_i} = prob\{r+g+b \leqslant 3n_i\} = \sum_{r+g+b\leqslant 3n} P^I_{r,g,b}, \quad n_i = \frac{r_i+g_i+b_i}{3} \tag{8}$$

For each pixel, an intensity level $n_i$ is defined. CDF and PDF are calculated based on this definition. Output intensity is calculated as $C^I_{R_i,G_i,B_i} \times L$ for each $n_i$ and with a hue preserving approach, $(R_O, G_O, B_O)$ is calculated. The aim of this method is color histogram equalization in a way that produces a uniform histogram in the grayscale [4]. Grayscale PDF of the resulted color image of this method is quite uniform in many cases but in this method correlation is ignored and over-enhancement is still there. The method introduced in this paper, with respect to the correlation between channels of each image; tries to find a suitable value for each pixel based on the principal component analysis. These values are calculated based on the correlation and variation of R, G and B values in the input image and therefore it is expected that the resulted R, G and B which are produced by equalization of these values, show better preservation of brightness of the input image along with the improvement of the image appearance and contrast. After equalization, with a hue preserving method the new R, G and B are calculated. The proposed method is faster and its output images are more visually appealing and distribution of its intensity component in the HSI space is more uniform.

## 3. Proposed method

Principal Component analysis [18,19] is a statistical method of data analysis. It is a simple and nonparametric method of variable reduction. When there are some redundant variables and it is possible to reduce the number of these variables by removing the correlation between them, PCA is a suitable choice. It is a mathematical procedure to convert a set of correlated variables into uncorrelated variables called principal components. Let $A$ be a data matrix each row of which is an observation and its columns are features. PCA is a mathematical method for converting the covariance matrix of the original data into a diagonal matrix. It means that PCA transforms data to a new space in which features