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Image illumination enhancement with an objective no-reference measure of illumination assessment based on Gaussian distribution mapping

Gholamreza Anbarjafari [a, *], Adam Jafari [b], Mohammad Naser Sabet Jahromi [c], Cagri Ozcinar [d], Hasan Demirel [e]

[a] University of Tartu, iCV Group, IMS Lab, Institute of Technology, Nooruse 1, Tartu 50411, Estonia
[b] PSJ, 222 Regent Street, London W1B 5TR, UK
[c] Hasan Kalyoncu University, Dept. of Electrical and Electronic Eng., Gaziantep 27470, Turkey
[d] Centre for Vision, Speech and Signal Processing, University of Surrey, Guildford GU2 7XH, UK
[e] Eastern Mediterranean University, Dept. of Electrical and Electronic Eng., Gazimagusa, KKTC, via Mersin 10, Turkey

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ABSTRACT

Illumination problems have been an important concern in many image processing applications. The pattern of the histogram on an image introduces meaningful features; hence within the process of illumination enhancement, it is important not to destroy such information. In this paper we propose a method to enhance image illumination using Gaussian distribution mapping which also keeps the information laid on the pattern of the histogram on the original image. First a Gaussian distribution based on the mean and standard deviation of the input image will be calculated. Simultaneously a Gaussian distribution with the desired mean and standard deviation will be calculated. Then a cumulative distribution function of each of the Gaussian distributions will be calculated and used in order to map the old pixel value onto the new pixel value. Another important issue in the field of illumination enhancement is absence of a quantitative measure for the assessment of the illumination of an image. In this research work, a quantitative measure indicating the illumination state, i.e. contrast level and brightness of an image, is also proposed. The measure utilizes the estimated Gaussian distribution of the input image and the Kullback-Leibler Divergence (KLD) between the estimated Gaussian and the desired Gaussian distributions to calculate the quantitative measure. The experimental results show the effectiveness and the reliability of the proposed illumination enhancement technique, as well as the proposed illumination assessment measure over conventional and state-of-the-art techniques.

1. Introduction

Contrast enhancement is frequently referred to as one of the most important issues in image processing [1–3]. The difference in visual properties makes an object distinguishable from other objects and the background. The information may be lost in areas where contrast is highly concentrated on a specific range. The problem is to optimize the contrast of an image in order to represent all the information in the input image. There have been several techniques to overcome the problem [4–9]. One of the most frequently used techniques is general histogram equalization (GHE) [10,11]. Later enhanced versions of GHE, such as local histogram equalization (LHE), were developed. However, the contrast issue remains, and recently many techniques for image equalization have been proposed, such as dynamic histogram equalization (DHE) [12] which improves image illumination by using histogram equalization on very specific partitions of the histogram, brightness preserving dynamic histogram equalization (BP-DHE) [13,14] which normalizes the brightness of the image in order to preserve the brightness of the input image in the output, singular value equalization (SVE) which enhances the illumination of an image by updating the largest singular value of the given image, and discrete wavelet transform (DWT) based SVE [15–17] which updates the

* Corresponding author. Tel.: +372 737 4855.
E-mail address: shb@ut.ee (G. Anbarjafari).
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largest singular value of the low–low subband of an image based on the corresponding singular value on the image after being equalized by using histogram equalization. In addition to the contrast issue, there are many algorithms aimed at improving illumination in specific regions of the image. There are several types of problems for which these algorithms are proposed, such as if an image is unevenly illuminated (e.g. a portion of the image is in dark shadow) and another portion is in overly bright sunlight, then we usually want to improve the contrast in both parts of the image without creating an unnatural result [1,18–20].

There are several instances where due to different environmental factors it's not always possible to get a suitably illuminated image. For example, machine learning and object recognition techniques may lose their effectiveness if the illumination of the images changes due to the cloudiness of the sky [21–23].

In this work, a Gaussian distribution (GD) mapping-based image illumination enhancement is proposed. The aim of the proposed technique is to map the cumulative distribution function (CDF) of the GD of the input image onto the CDF of a desired GD in order to calculate the new pixel values of the enhanced image. The proposed illumination enhancement technique can be used as a pre-processing step for many other algorithms in order to improve their final results.

When analysing illumination methods other than visual analysis evaluation (i.e. subjective evaluation), there is no objective quantitative method to assess the illumination of the enhanced images. Some researchers use the mean opinion scores (MOS) in order to compare different illumination techniques; however, MOS is a subjective metric. Other image quality metrics, like the Face Quality Index, combine different properties (e.g. contrast, brightness, sharpness, illumination) of an image to achieve a metric used specifically in face recognition [24]. There is also a Universal Quality Index (UQI) that performs well if image distortion is being analysed [25]. Another common approach is to use a peak signal-to-noise ratio (PSNR) to assess the quality of an image. Using PSNR might be a good approach for a consistent, fixed content signal, but when applied to images or videos, it gives incomparable results across multiple contents [26]. Also it is important to note that in the case of illumination enhancement assessment, the absence of the ground truth limits the use of some the aforementioned techniques. There exist measures that try to deal with no-reference (NR) quality measurement. These approaches use machine learning techniques such as sparse extreme learning machine and neural networks [27–29]. They are based on the human visual system and try to emulate the MOS. Among other NR image quality assessment measures, methods have been developed to measure blur [30] and even colour harmony [31], but as yet not the illumination quality. In this paper we define a notation of an ideally illuminated image that will be the reference point for our metric. This does not fix one specific image but rather describes the properties that a mathematically ideal image should have.

We are proposing a new quantitative measure for image illumination quality which is based on finding the Kullback-Leibler Divergence (KLD) between an estimated Gaussian distribution of a given image and the desired Gaussian distribution. The desired Gaussian distribution can be chosen in a way that satisfies all the required and necessary features of an ideal enhanced image. The proposed metric generates a numerical value between −1 and 1 to reflect the quantitative assessment of illumination of a given image without using a ground truth image. A positive numeric value represents a high contrast image, and the negative value corresponds to a low contrast image. If the numeric value is in the (−0.5, 0.5) range, then the image is a dark image; otherwise it is a bright image. By using the proposed metric, all four possible image illumination quality cases (namely: low contrast-dark, low contrast-bright, high contrast-dark and high contrast-bright) can be represented.

Section II introduces the proposed image illumination enhancement technique based on GD mapping. In Section III the proposed image illumination assessment measure that is used to assess the illumination of an image is introduced. Section IV presents experimental results obtained using the image illumination enhancement technique and analyses their illumination state with the proposed measure.

2. Proposed Gaussian distribution mapping based image illumination technique

The main aim of this illumination enhancement is to change the brightness and contrast of an image into "better" or "desired" brightness and contrast. The "desired" brightness and/or contrast are defined based on the application by the users or experts. In the proposed technique, there exist two parallel stages:

1. Based on the application, the mean and variance of "desired" brightness and contrast should be defined. Brightness is addressed by indicating the mean, μ_d, of the intensity image, and contrast is addressed by indicating the variance, σ_d^2, of the intensity image. After specifying the μ_d and σ_d^2, a Gaussian distribution (GD) will be assigned to this "desired" illumination by using the following equation:

$$G_d\left(\mu_d, \sigma_d^2\right)(x) = \frac{1}{\sqrt{2\pi\sigma_d}} e^{-\frac{(x-\mu_d)^2}{2\sigma_d^2}} \tag{1}$$

where $x \in [0,255]$ for an 8-bit grey scale image. Then the cumulative distribution function (CDF) of this GD is calculated, as shown in eqn. (2).

$$CDF_{GD}(x) = \frac{1}{2}\left[1 + \frac{1}{\sqrt{\pi}} \int_{-\frac{x-\mu}{\sqrt{2}\sigma}}^{\frac{x-\mu}{\sqrt{2}\sigma}} e^{-t^2} dt\right] \tag{2}$$

2. In parallel, the mean, μ_{im}, and variance, σ_{im}^2, of the input image is calculated, and the GD assigned to these values is generated by using the general formula shown in eqn. (1). Similarly the CDF of this GD is also calculated.

These two steps are used to produce mapping of the image pixel values onto the new equalized values. For this purpose, the following procedure is followed:

1. Calculate the CDF value of a given intensity pixel value from the CDF_{im}.
2. Find the intensity pixel value that corresponds to the CDF value calculated in step 1 on CDF_d.

Using the aforementioned mapping procedure, a new table of pixel values will be generated. This table will be used in order to obtain the enhanced image. The graphical representation of the proposed technique is illustrated in Fig. 1. In the next section, based on the definition of desired GD, G_d, and image's GD, G_{im}, a measure will be introduce which can be used for illumination assessment.