Engineering Applications of Artificial Intelligence 26 (2013) 1487–1492

Contents lists available at SciVerse ScienceDirect

Engineering Applications of Artificial Intelligence

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

Image contrast enhancement for preserving mean brightness without losing image features

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ARTICLE INFO

Article history:
Received 15 July 2012
Received in revised form
6 September 2012
Accepted 29 November 2012
Available online 29 January 2013

Keywords:
Contrast enhancement
Histogram equalization
Image quality evaluation

ABSTRACT

Histogram equalization is a well-known and effective technique for improving the contrast of images. However, the traditional histogram equalization (HE) method usually results in extreme contrast enhancement, which causes an unnatural look and visual artifacts of the processed image. In this paper, we propose a novel histogram equalization method that is composed of an automatic histogram separation module and an intensity transformation module. First, the proposed histogram separation module is a combination of the proposed prompt multiple thresholding procedure and an optimum peak signal-to-noise ratio (*PSNR*) calculation to separate the histogram in small-scale detail. As the final step of the proposed process, the use of the intensity transformation module can enhance the image with complete brightness preservation for each generated sub-histogram. Experimental results show that the proposed method not only retains the shape features of the original histogram but also enhances the contrast effectively.

1. Introduction

Over the last few decades, visual image quality has been actively improved using contrast enhancement techniques, which are increasingly necessary for the design of digital multimedia systems, such as video surveillance systems (Havasi et al., 2007; Eng et al., 2008), digital photography (Oakley and Bu, 2007; Fattal, 2008), medical imaging systems (Chen et al., 2005; Yang et al., 2009), and low power systems (Lai and Tsai, 2008). Moreover, contrast enhancement has become widely available to provide a "better" transform representation for real image processing systems with both software and hardware environments, including Photoshop (Chen et al., 2006a), mobile devices, digital TV, and digital cameras (Kim et al., 2001; Kim, 1997; Wang et al., 1999; Sim et al., 2007).

In recent years, contrast enhancement techniques have been used in many digital multimedia systems, such as for object tracking in video surveillance systems (Chen et al., 2008), radiography applications (Dippel et al., 2002), arterial visualization of medical imaging (Bemmel et al., 2003), tumor microcirculation (Koh et al., 2003), virtual restoration of ancient Chinese paintings (Pei et al., 2004), vision impairment estimation (Tang et al., 2004), recovery of underwater visibility (Schechner and Karpel, 2005), bas-relief generation (Sun et al., 2009), and face recognition (Xie and Lam, 2005). Therefore, the aim of this study is to develop a high-performance contrast enhancement method that fits the current requirements (Perner et al., 1999; Shin et al., 1992; Zhang et al., 2010).

Contrast enhancement methods can be broadly categorized into two major classes: direct and indirect methods (Arici et al., 2009). Direct methods (Beghdadi and Negrate, 1989; Cheng and Xu, 2000) try to improve image using the definition of a contrast measure. Indirect methods (Sherrier and Johnson, 1987; Polesel et al., 2000) exploit the under-utilized dynamic range of the images to improve contrast without a contrast measurement. Almost all the most popular contrast enhancement methods in the literature fall into the second category (Arici et al., 2009). Furthermore, the indirect methods can be divided into two sub-classes: histogram modification techniques (i.e., spatial domain techniques) and transform domain techniques (Arici et al., 2009; Hanmandlu and Jha, 2006). In particular, histogram modification techniques have attracted significant attention from researchers due to their simplicity and computational efficiency.

Generally speaking, histogram modification techniques can be categorized into two main types, global histogram modification and local histogram modification (Kim et al., 2001; Lamberti et al., 2006). Global histogram modification techniques attempt to modify the spatial histogram of an image in order to closely match a uniform distribution via the transform function. This is generated by using the histogram information of the entire input image (Abdullah-Al-Wadud et al., 2007). However, global histogram modification technique cannot adapt to local brightness features. This causes limitations in the amount of contrast enhancement in

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http://dx.doi.org/10.1016/j.engappai.2012.11.011

some parts of the image (Chen et al., 2006a; Abdullah-Al-Wadud et al., 2007).

A direct extension of global histogram modification is termed local histogram modification. In order to efficiently improve the visibility of the small-scale detail, local histogram modification techniques independently equalize each sub-histogram on the basis of histogram separation (Chen et al., 2006b). However, local histogram modification techniques sometimes cause over-enhancement and noise-enhancing artifacts in some portion of an image (Abdullah-Al-Wadud et al., 2007).

A good contrast enhancement technique should specifically address several significant properties, some of which are listed below.

(1) Noise tolerance: The contrast enhancement technique should exhibit appropriate noise immunity.
(2) Uniform contrast: The contrast enhancement technique should provide uniform contrast of the entire image.
(3) Brightness preservation: The contrast enhancement technique should enhance the contrast of the image without losing brightness.
(4) Convenient implementation: The contrast enhancement technique should be able to be set up quickly and reliably.

In this paper, a novel contrast enhancement method is presented to enhance the contrast of an image without losing the original histogram characteristics. It is expected to eliminate the abovementioned drawbacks of the conventional global-based and local-based histogram modification methods effectively. The proposed method can be briefly described as follows:

1. Separation of a histogram with the proposed multiple thresholding procedure by using a prompt mean function and standard deviation.
2. Achievement of contrast enhancement by equalizing sub-histograms in small-scale detail.

Experimental results show that the proposed method gives more accurate results than other state-of-the-art methods in the case of a wide range of natural digital images. The performance of the proposed method will be demonstrated through qualitative and quantitative evaluations.

The rest of this paper is divided into Sections 2–5. In Section 2, we present a relatively compact overview of the popular histogram modification methods. Section 3 describes the proposed contrast enhancement method in detail. Section 4 presents a comparison of the experimental results of the proposed method and some of the other existing methods. Our concluding remarks are presented in Section 5.

2. Related work

Known as one of the most popular contrast enhancement techniques, histogram equalization (HE) can efficiently perform contrast enhancement because of its simplicity and effectiveness. The basic idea of the HE method is to re-map the gray levels of an input image using a transformation function with the cumulative distribution of the input image. HE attends to and stretches the dynamic range of the image histogram to improve the overall contrast of the original image. However, the HE method is unsuitable for consumer electronic applications because the calculated transformation function may significantly change the brightness of the original input image.

To overcome this problem, several researchers have studied the preservation of image brightness in HE-based enhancement methods. In 1997, brightness preserving bi-histogram equalization (BBHE) (Kim, 1997) was proposed for separating an image histogram into two sub-histograms with the mean of the gray-level for the input image before equalizing them independently. Later, Wang et al. (1999) proposed dualistic sub-image histogram equalization (DSIHE) for separating a histogram on the basis of the median instead of the mean of the gray levels. Sim et al. (2007) proposed recursive sub-image histogram equalization (RSIHE) by extending DSIHE (Wang et al., 1999). In RSIHE (Sim et al., 2007), the median-based histogram separation is applied several times to obtain the local median values, whereas DSIHE (Wang et al., 1999) performs the separation only once.

Although the HE method can attain a significant improvement in image contrast, the equalized image may distort the mean brightness of the input image (Kim, 1997). Because the BBHE (Kim, 1997) method only performs the local histogram equalization with one separation, the enhanced image may contain an extreme over-enhancement and noise artifacts. Further, because the DSIHE method (Wang et al., 1999) is similar to the BBHE method (Kim, 1997) with respect to a single histogram separation, an image enhanced using DSIHE may contain an extreme over-enhancement and noise artifacts. Although the RSIHE method (Sim et al., 2007) is better than the traditional HE, BBHE (Kim, 1997), and DSIHE (Wang et al., 1999) methods, some serious over-enhancement and noise artifacts still exist in the enhanced image because of the number of sub-histograms generated experimentally using the calculated local median values. As mentioned before, the number of sub-images and its corresponding calculation of threshold determination necessitate the development of an effective histogram equalization algorithm.

3. Proposed method

In this section, we propose a novel contrast enhancement method, which involves two important modules: a histogram separation module and an intensity transformation module. First, the proposed histogram separation module is a combination of the proposed prompt multiple thresholding procedure and an optimum *PSNR* calculation to separate the histogram in small-scale detail. As the final step of the proposed process, the use of the intensity transformation module can enhance the image with complete brightness preservation for each generated sub-histogram.

3.1. Histogram separation

Each $M \times N$ discrete input image I_{xy} can be defined as an M-by-N matrix, where xy denotes an arbitrary pixel in the spatial domain. The matrix of the original image I_{xy} is expressed as follows:

$$I_{xy} = \begin{bmatrix} I_{0,0} & I_{0,1} & \cdots & I_{0,N-1} \\ I_{1,0} & I_{1,1} & \cdots & I_{1,N-1} \\ \vdots & \vdots & \ddots & \vdots \\ I_{M-1,0} & I_{0,1} & \cdots & I_{M-1,N-1} \end{bmatrix}. \quad (1)$$

(1) Prompt multiple threshold selection: Suppose that an input image I is composed of G discrete intensity levels; thus, the statistical histogram H of an input image I is expressed as follows:

$$H(h) = n_h \quad \text{where } h = 0,1,2, \ldots, G-1. \quad (2)$$

Note that n_h represents the number of pixels that correspond to the intensity h of the input image I. Based on the statistical histogram H of the input image I, the mean value μ can be