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A flexible contrast enhancement method with visual effects and brightness preservation: Histogram planting☆

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ABSTRACT

Even in contrast, no technique can be claimed to be the best for all kinds of images. When other criteria, such as visual effects and brightness preservation, are considered simultaneously, it is much harder to find the optimal method. For balancing contrast and visual effects, and even brightness preservation, a flexible contrast enhancement method, called histogram planting (HP), is proposed to promote the overall quality of an image. HP is a very promising redistribution method. It first groups histogram components, and then redistributes these grouped grey levels over a specified range through two distributions: an equality-spaced distribution and a proportionality-spaced distribution. For better brightness preservation, each type further performs multiple subhistograms. In terms of contrast and visual effects, and even brightness preservation, experimental results show that the proposed HP-based methods do provide enough contrast enhancement, pleasing appearances and even good brightness preservation for a wide range of images.

1. Introduction

Contrast enhancement is a widely used tool in image processing [1–5]. Xu et al. [1] assessed the vascularization of hydroxyapatite orbital implants by comparing contrast-enhanced ultrasound and contrast-enhanced magnetic resonance imaging (MRI). Ahn et al. [2] compared the diagnostic performance of contrast-enhanced MRI and non-contrast-enhanced MRI for adhesive capsulitis. Gandhamal et al. [5] used a generalized contrast enhancement technique for medical images to improve visual information for obtaining quantitative measurements from medical images.

Low-contrast images may result from poor illumination, limited dynamic ranges, or even wrong settings of lens apertures during image acquisition [6]. Contrast enhancement aims to raise the contrast of an image so that hidden details and features can be clearly revealed. However, no technique can be fully applicable to all kinds of images under its claimed effects. Sometimes they invoke excessive enhancement for some images, thereby damaging visual effects; sometimes they even lower the contrast for other images. Basically, a good contrast enhancement method should keep visual effects while raising contrast as much as possible, and/or preserving enough brightness, especially for consumer electronics such as TVs.

Among contrast enhancement methods, some only focus on contrast, some concern brightness preservation as well as contrast, and some consider visual effects as well as contrast. The first class includes histogram equalization (HE) [6], grey-level grouping (GLG) [7], and dynamic histogram equalization (DHE) [8]. HE aims to transform the histogram of an image into a uniformly distributed shape. However, the output histogram generally is not uniformly distributed due to the discrete

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nature of a digital image, and thus unnatural appearances are often induced in the contrasted image. Even worse, its average brightness is always towards the middle of the grey scale, which yields monotonic visual effects extremely unsuitable for consumer electronics. In order to achieve maximum contrast enhancement and produce satisfactory results for low-contrast images, Chen et al. [7] proposed a GLG method to automatically distribute histogram components according to the maximum average distance (AD) between pixels on the grey scale. However, GLG easily induces patchiness effects at the highest grey level, and hence Chang et al. [9] proposed a GLG with a limit to improve visual effects of an image. On the other hand, DHE was proposed to effectively take control over the effects of HE. DHE first partitions an image histogram into subhistograms based on the local minima of a smoothed histogram, assigns a specified grey level range to each partition, and equalizes them individually.

The second class further considers brightness preservation. Kim [10] proposed brightness preserving bi-histogram equalization (BBHE): The histogram of an input image is first divided into two subhistograms based on the mean of its input image, and then equalizes them independently. Similar to the concept of BBHE, Wang et al. [11] proposed dualistic sub-image histogram equalization (DSIHE), which divides an input histogram into two subhistograms based on the median of its input image. BBHE and DSIHE do provide good brightness preservation, but also limits the level of contrast enhancement accordingly.

In order to achieve the maximum brightness preservation, Chen and Ramli [12] proposed minimum mean brightness error bi-histogram equalization, which finds the minimum absolute difference between an input image mean and its corresponding output image and then determines the grey level of dividing the input histogram. On the other hand, Wang and Ye [13] proposed brightness preserving histogram equalization with maximum entropy, which produces an ideal histogram with brightness preservation and then applies histogram specification to obtain the transformed histogram.

As an extension of BBHE, Chen and Ramli [14] proposed a scheme called recursive mean-separate histogram equalization (RMSHE) to achieve higher brightness preservation. RMSHE may provide adjustable brightness preservation, but how to choose an appropriate iteration number is still a challenge. Similar to RMSHE, Sim et al. [15] proposed a technique to raise brightness preservation, called recursive sub-image histogram equalization (RSIHE), which uses the median, rather than the mean, to decompose an input histogram. RMSHE and RSIHE may generally improve the results enhanced by BBHE and DSIHE, respectively, but also invoke a potential problem of how to choose the repeating number for segmenting.

Since DHE does not take brightness preservation into consideration, Ibrahim and Kong [16] further proposed brightness preserving dynamic histogram equalization (BPDHE). BPDHE first partitions the image histogram based on the local maxima of a smoothed histogram, instead of the local minima, assigns a new dynamic range to each partition, and equalizes these partitions independently. Finally, the output intensity is normalised to make the mean of the resulting image equal to the input image.

The third class considers both visual effects and contrast. Wang and Ward [17] proposed a simple and effective mechanism to control the distributed proportion of each histogram component, called weighted thresholded histogram equalization (WTHE). Their results normally show more pleasing visual effects than some HE-based methods at the expense of contrast. On the other hand, Arici et al. [18] enhanced images by a histogram modification framework, where the modified histograms are obtained by minimizing some specific cost functions. They introduced specifically designed penalty terms to adjust the level of contrast enhancement. Since some modified histograms, such as histogram smoothing and weighted histogram approximation, are the forms of matrix multiplication and inversion, they finally proposed a low-complexity algorithm, called the histogram modification algorithm (HMA), to reduce computational cost and raise visual effects.

In order to solve patchiness effects and/or washed-out appearances, Chang and Chang [19] proposed a simple histogram modification scheme according to the characteristic of implementation. The scheme is very appropriate for all histogram-related methods, including histogram equalization, histogram specification and histogram redistribution.

For effectively utilizing the contextual information around each pixel, Celik proposed a two-dimensional histogram equalization (2DHE) algorithm to enhance the contrast of an image [20]. The logic of the algorithm is that the contrast of an image can be improved by increasing the differences between pixels. Since 2DHE only requires some simple arithmetic operations, it is easy to implement; however, it needs a multilevel nested loop to obtain a 2D histogram, and therefore it is a considerably time-consuming task.

Most existing techniques were proposed to solve certain specific problems; sometimes one is superior to another for some images, and sometimes it loses its advantages for other images. In this paper, a histogram redistribution method, called histogram planting (HP), is proposed to balance contrast enhancement, visual effects and even brightness preservation. In the future, the HP method can easily be extended to local or adaptive contrast enhancement as done by local histogram equalization [21] and further applied to related fields [22,23]. Because the original histogram components can be grouped and then redistributed to any interval, the concept of contrast limited adaptive histogram equalization [24] is similar to selecting a distributed interval.

The paper is organised as follows. Section 2 presents the proposed HP. Experimental results are illustrated and discussed in Section 3. Section 4 concludes the paper with some facts.

2. Histogram planting

In the previous section, the implementation of contrast enhancement for histogram-based techniques was described briefly, where HE and GLG only consider enhancing contrast and some techniques such as BBHE and DSIHE have incor-

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