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Semi dynamic fuzzy histogram equalization

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ABSTRACT

Conventional histogram equalization is a widely used technique for contrast enhancement, but it usually over-enhances the contrast of the images resulting into loss to their natural appearance. To overcome this problem, histogram segmentation prior to equalization process has been suggested in the literature. Although these methods significantly enhance the contrast but usually fail to preserve the natural appearance of the images. In this paper, a fuzzy-HE method to preserve the brightness and natural appearance of the images is proposed. It decomposes the fuzzy histogram of the input image into two segments using median value of occupied intensities. Prior to equalization process, the narrow segment is identified and allocated with new dynamic range. Finally the combined equalized sub-histograms are normalized to avoid intensity saturation and un-even distribution of bins. The simulation results show that the proposed method yields better results both qualitatively and quantitatively.

1. Introduction

The conventional histogram equalization (CHE) method has been suggested as simple and most effective technique for contrast enhancement of digital images [1]. It maps the input intensity levels into new intensity levels by utilizing the cumulative distribution function (cdf) of input image. By performing such mapping, the overall contrast enhancement of input image can be achieved by stretching the dynamic range of its original histogram.

In order to understand CHE, consider the input image $I(i,j)$ having L number of discrete intensity levels $X_0, X_1, \ldots, X_{L-1}$ (for 8-bit image, $L = 256$). For simplicity κth intensity level X_k is denoted by k. The probability distribution function (pdf) for kth intensity level is defined in the following equation:

$$p(k) = \frac{n(k)}{\left(\sum_{k=0}^{L-1} n(k)\right)} = \frac{n(k)}{N} \tag{1}$$

where $k \in [0, L-1]$, $n(k)$ is number of pixels with kth intensity level, and $N (= u \times v)$ is total number of pixels in the image having dimensions $u \times v$. The cdf for kth intensity level $c(k)$, as defined in Eq. (2) is the summation of pdf of all previous intensity levels including $p(k)$ itself, that is:

$$c(k) = \sum_{q=0}^{k} p(q) \quad \forall k \in [0, L-1] \tag{2}$$

Note that $c(L-1)$ is always unity. Now this cdf value acts as transformation (or mapping) function which maps the input intensity level to new intensity level. Consider T as a transformation function which maps the input intensity level k into new output intensity level $T(k)$, which is defined in the following equation:

$$T(k) = ||(L-1) \times c(k)|| \tag{3}$$

where $||x||$ is nearest integer function value of x. Thus the output image $O(i,j)$ can be seen as transformed version of input image $I(i,j)$:

$$O(i,j) = T[I(i,j)] \quad \forall (i,j) \in I \tag{4}$$

Despite its popularity, CHE normally introduces undesirable visual artifacts in the processed images due to either excessive brightness shift [2,3], or over enhancement of noisy regions [4,5], or saturation of intensities [6,7]. To overcome these limitations of CHE method, numerous solutions have been suggested in the literature [2–11].

Brightness preserving bi-histogram equalization (BBHE) [2] and dualistic sub-image histogram equalization (DSIHE) [3] methods are amongst the earliest approaches, which tries to control the excessive brightness shift of processed images, by dividing the input image histogram into two sub-histograms and then

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equalizing them (sub-histograms) independently. Another method known as minimum mean brightness error bi-histogram equalization (MMBEBHE), which is quite complex compared to BBHE and DSHIE has also been developed [8]. The high complexity of MMBEBHE method is due to searching of minimum absolute mean brightness error (AMBE) value between input and output mean values. These methods usually shift image brightness to higher extent and introduce visual artifacts in low contrast images.

Above mentioned techniques are also extended for multi-histogram equalization in which histogram of input image is segmented into more than two sub-histograms, and then each segment is equalized independently. Among multi-HE methods, recursive mean-separate histogram equalization (RMSHE) [9] and recursive sub-image histogram equalization (RSIHE) [10] can be seen as extensions of BBHE [2] and DSIHE [3] methods, respectively. It has been reported that, compared to bi-HE methods, RMSHE and RSIHE methods hold better brightness preservation property for larger values of γ (where, γ is recursive segmentation value). However, for larger value of γ, the output image histogram tends to be similar to that of input image histogram without any contrast enhancement [11]. These multi-HE methods also suffer with major limitation of ineffective expansion of sub-histograms, i.e. when CHE method is applied to large number of segments, it may not expand their dynamic range effectively, thereby resulting into visual artifacts in the processed images.

Another attempt to improve BBHE by setting plateau limits to histogram peaks have been made in [7,13], and referred as bi-histogram equalization median plateau limit (BHEPL-D) [7], and bi-histogram equalization plateau limit (BHEPL) [13]. By setting plateau limits to histogram peaks, the intensity saturation and over-enhancement problems can be avoided.

To overcome the limitation of simple Multi-HE methods (i.e. RMSHE etc.), the Dynamic HE (DHE) method has been suggested [14]. DHE segments the histogram of input image and assigns a new dynamic range to each sub-histogram based on the original dynamic range and the number of pixels in the corresponding segment. Although DHE is very effective for dark images, it fails to preserve the brightness of the images [15].

In order to avoid intensity saturation artifacts, a hybrid approach of plateau clipping and DHE has also been suggested and referred as, quadrants dynamic histogram equalization (QDHE) [6], and dynamic quadrants histogram equalization plateau limit (DQHEPL) [7]. However, it is observed that the intensity saturation is not the only problem that should be avoided, but expansion of intensity levels after HE process on each segment, also plays a vital role i.e. it is necessary that equalization process on each segment should expand the intensity levels evenly. To overcome the limitations of brightness shift, visual artifacts and intensity saturation in the processed images, many other HE methods have also been developed [16–20].

In order to overcome the problem of excessive brightness shift, fuzzy-based method has also been proposed [12]. Compared to conventional histogram, the fuzzy statistics (or fuzzy histograms) are expected to handle the imprecision in intensity levels more effectively, and considers the exactness of intensity values and do not require smoothing to achieve useful partitioning. The efficiency of fuzzy histogram strongly depends on the appropriate selection of fuzzy membership function (MF), and resulting histograms have better control on random fluctuations or missing intensity levels [12]. However, inclusion of fuzzy histogram might increase the complexity of the algorithm.

This paper proposes a novel modification of Bi-HE method, which ensures that pixel intensities within each segment are expanded evenly while avoiding intensity saturation problem to preserve the natural appearance of the images. The proposed method segments the fuzzy histogram of input image into two sub-histograms using median of occupied intensities as threshold value. The low contrast dark (or bright) image histogram when segmented to multiple parts may result into narrow ranged segments as compared to other segments. When CHE is applied to these narrow segments, it may lead to improper contrast enhancement. In order to overcome this limitation, the propose method first allocates full dynamic range to the narrow segment before application of CHE. The proposed method is referred as semi dynamic because it allocates full dynamic range to only one segment (out of two). In order to ensure even expansion of intensities, the final step involves the application of normalization function, so that the natural appearance of the image can be preserved more precisely.

Remainder of the paper is organized as follows: Section 2 presents the details of the proposed method. Simulation results and discussions are given in Section 3, and finally paper is concluded in Section 4.

2. Proposed method

As discussed in the previous section, the objective of the proposed method is to avoid excessive brightness shift, over enhancement of noisy background, and to preserve the natural appearance of the images. These objectives can be achieved by avoiding saturation and un-even expansion of intensities. Therefore, the proposed method allocates a new full dynamic range to narrow segments and uses a normalization function to solve these problems In the proposed algorithm, the fuzzy histogram of input image is segmented via median value of occupied intensities, and then narrow segments are identified and expanded to the full dynamic range $[0,L-1]$ (or $[X_0,X_{L-1}]$) before applying the CHE to each segment, while the other segments are equalized within their original dynamic range. Finally the equalized image is normalized. The proposed algorithm consists of five modules: fuzzy histogram, histogram segmentation, expansion of narrow segments, equalization and normalization of intensities. The complete algorithm is described in following sub-sections.

2.1. Fuzzy histogram

The crisp statistics (or conventional histogram) do not consider the inexactness of intensity values and it needs smoothing to achieve useful partitioning. The fuzzy statistics can handle the imprecision in intensity levels more effectively. The efficiency of fuzzy histogram strongly depends on the appropriate selection of fuzzy membership function (MF), and resulting histograms have better control on random fluctuations or missing intensity levels [12].

A fuzzy histogram consists of a sequence of real numbers $n(k)$, where $n(k)$ is the frequency of occurrence of intensity levels around kth level. Let intensity value $I(x, y)$ is considered as fuzzy number $\tilde{I}(x, y)$. The fuzzy histogram can be obtained according to the following equation:

$$\tilde{n}(k) = n(k) + \sum_x \sum_y \mu_{\tilde{I}(x,y)k} \tag{5}$$

where $\mu_{\tilde{I}(x,y)k}$ represents triangular membership function which is defined in the following equation:

$$\mu_{\tilde{I}(x,y)k} = \max\left(0, 1 - \frac{\left|I(x,y) - k\right|}{2}\right) \tag{6}$$

2.2. Histogram segmentation module

The proposed method segments the input image histogram into two segments using median value of occupied intensities. Assume