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Image contrast enhancement using normalized histogram equalization

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ABSTRACT

This paper proposes a modification of histogram equalization method, which enhances the contrast of the image while preserving its brightness and natural appearance. The proposed method avoids uneven expansion of intensities by allocating full dynamic range to narrow ranged segments produced after segmentation process, and each segment is equalized independently. In order to avoid intensity saturation problem, a normalization of intensities is also suggested. Simulation results show that the proposed method outperforms other contemporary methods both qualitatively and quantitatively. It enhances the contrast of the image and preserves its brightness and natural appearance more precisely. The statistical consistency of results is verified using ANOVA statistical tool.

1. Introduction

From past few years, multimedia cell-phones have gained a lot of popularity because of the embedded high definition cameras. However, the pictures captured in low-light environment are of low contrast constituting mainly dark pixels. The images especially taken at night from long ranges are today's major concern. Light emitting diodes (LED's) in dark environment can be used as a light source for closer objects; however it fails to act as a proper source of illumination for long ranges.

The histogram equalization (HE) method is demonstrated as a simple and widely accepted technique for contrast enhancement of images [1]. It achieves overall image contrast enhancement by expanding the dynamics range of the histogram using cumulative distribution function (cdf) as a transformation function. Despite of its simplicity, conventional HE (CHE) normally introduces undesirable visual artifacts in the processed images, due to excessive brightness shift and saturation of intensities. To overcome these limitations, several multiple segmentation approaches have been suggested in the literature [2–11].

Multiple segmentation approaches divides the histogram of the input image into multiple non-overlapping sub-histograms (segments) i.e. into two or more than two sub-histograms. Among them, brightness preserving bi-histogram equalization (BBHE) [2], and dualistic sub-image histogram equalization (DSIHE) methods [3] are popular ones. They partition the image histogram into two sub-histograms using the mean or median intensity as threshold and then each sub-histogram is equalized independently. These methods achieve good contrast enhancement, but processed images usually suffers with problems of brightness shift and intensity saturation artifacts.

To further preserve the brightness and natural appearance of the input images, the histogram has been partitioned into more than two segments [4–6]. In this category, recursive mean-separate histogram equalization (RMSHE) [4] and recursive sub-image histogram equalization (RSIHE) [5] are the extensions of BBHE and DSIHE methods respectively. However, partitioning image histogram into large number of non-overlapping sub-histograms may preserve the image brightness but lacks significant contrast enhancement. Two minimum within class variance based histogram segmentation methods has also been developed [6]. Although these methods are able to preserve the brightness of the image, suffers with intensity saturation problem.

The aforementioned algorithms usually cluster sub-histogram boundaries around larger probability regions (high peaks), resulting into narrow range sub-histograms (segments), as shown in Fig. 1. The application of HE over these narrow ranged sub-histograms constituting high peaks may result into annoying artifacts in the processed images. In order to overcome this drawback, the Dynamic HE (DHE) method has been suggested [7]. DHE expands the sub-histograms to a new dynamic range by using a function depending on number of pixels in the corresponding sub-histogram. This means, the sub-histograms constituting higher number of pixels occupies larger range compared to other

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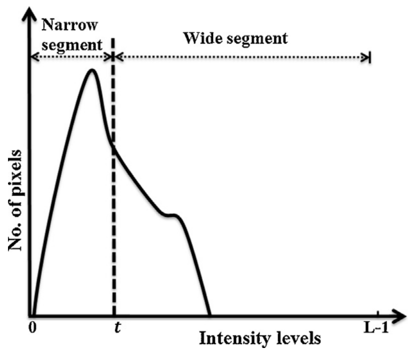

Fig. 1. Effect of high probability regions on histogram segmentation.

sub-histograms. However, DHE method under low light conditions suffers with intensity saturation problems and produces undesirable visual artifacts [8].

In order to avoid intensity saturation problem, the plateau based methods have been suggested in the literature. These methods clip the peak of the histogram to some extent, so that the intensity levels having high values (large population of pixels having same value) can be prevented from expanding to high range. By performing clipping process, high probability regions of the histogram may be prevented from dominating over its low probability regions. Some of the plateau based methods are bi-histogram equalization plateau limit (BHEPL) [9], bi-histogram equalization median plateau limit (BHEPL-D) [10], dynamic quadrants histogram equalization plateau limit (DQHEPL) [10], and quadrants dynamic histogram equalization (QDHE) [11].

The plateau based methods that preserves the brightness and natural appearance of the images are based on the assumption that the processed histograms having intensity saturation problem is the main reason of visual artifacts in the output images [9–11]. However it is observed that, in order to maintain the natural appearance of processed images, it is not only the intensity saturation that should be avoided, but also it is necessary that HE on each segment should expand the intensity levels evenly [17,18].

This paper proposes a modified HE method which preserves the natural appearance of the images by expanding the pixel intensities of each sub-histogram evenly while avoiding intensity saturation problem [17]. The proposed method segments the global histogram into non-overlapping sub-histograms by using within-class-variance as thresholds (boundaries). However, due to random nature of the images, it is expected that some sub-histograms may have closer boundaries with respect to others. Therefore these narrow sub-histograms may not have sufficient space for proper expansion, and HE over these narrow sub-histograms (compared to other wider sub-histograms) may result into insignificant contrast enhancement. Hence, prior to HE process over each segment, a new full dynamic range has been assigned to narrow ranged sub-histograms. After that, the intensities are normalized. By performing such process, it is expected that the histogram if the processed images can be prevented from saturation and un-even expansion of intensities.

Remainder of the paper is organized as follows: The related conventional HE technique is briefly described in Section 2. Section 3 presents the details of proposed method. The results are discussed in Section 4, and finally paper is concluded in Section 5.

2. Conventional HE

This section describes the basic definition of CHE method. The CHE uses the cumulative distribution function (cdf) as a mapping (transformation) function, which maps input intensity level to new intensity level. The mapping process is described below.

Consider the input image histogram H having L discrete intensity levels i.e. 0,1,. . .$L-1$ (for 8-bit image, $L = 256$). The probability distribution function (pdf) for kth intensity level is defined as:

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

where, $k \in [0, L-1]$, $n(k)$ is a number of pixels with kth intensity value, and N is the total number of pixels in the image. The cumulative distribution function (cdf) can be determined as integral of image histogram i.e.

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

where, $c(k)$ is the cdf at the kth intensity level. Utilizing the cdf value of each level, CHE maps the input intensity value to new intensity value. The transformation function (T) for intensity level k can be obtained from:

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

where, $||x||$ is nearest integer function value of x.

It is proven that the CHE tends to shift the mean brightness of the image to the mid-intensity level (i.e. $L/2$), which results into higher brightness shift for dark or bright images. It is worth noting that, mapping of intensities directly depends on height of the intensity levels, i.e. intensities having high peaks are expanded to larger extent compared to lower ones. Due to over and under enhancement of some regions, the processed image may appear noisy. In order to preserve the brightness of the processed image, the histogram may be segmented into multiple segments and each segment can be equalized independently.

3. Proposed method

As stated earlier, to avoid excessive brightness shift and intensity saturation artifacts, the histogram may be manipulated (e.g. clipping process) prior to equalization process. However, we observed that, to eliminate visual artifacts in the processed images, not only saturation but also un-even expansion of intensities should be avoided. Therefore, the proposed algorithm segments the histogram into multiple non-overlapping sub-histograms by using Otsu method [12]. Prior to equalization process, narrow sub-histograms are identified and expanded to full intensity range [0, $L-1$], while the other sub-histograms are equalized within their dynamic range. The proposed algorithm consists of four steps i.e. segmentation, expansion of narrow ranged sub-histograms, equalization and normalization of intensities. These steps are discussed in the following sub-sections.

3.1. *Segmentation process*

The proposed method segments the complete histogram into multiple non-overlapping sub-histograms by using optimal threshold that minimizes the within class histogram variance [12], then each segment is further separated into two parts utilizing same criteria, resulting into 2^R segments. In our case, $R = 2$. The generalized segmented histogram is defined below.

Let $H[k_l,k_u]$ be a histogram of input image $I(i,j)$ having k_l and k_u as lower and upper intensity value, segmented into n sub-histograms, can be represented as:

$$H[k_l, k_u] = \bigcup_{r=1}^{n} H_r[k_l^{r,n}, k_u^{r,n}] \tag{4}$$