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Parametric-oriented fitting for local contrast enhancement

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ABSTRACT

Local image contrast enhancement methods extract more informative details comparing with the global methods. Yet, the traditional schemes require to access all of the pixels in a local region to obtain the cumulative distribution function (cdf) for further enhancement, i.e., adaptive histogram equalization (AHE), and thus the time complexity drastically increases accordingly when the block size increases. Consequently, some speed-up ingenuities such as block-wise strategy and simple proportionally averaging manner are employed to cope with this issue, yet serious blocking artifact or low contrast issues are accompanied. In this study, a local enhancement method, namely corrected parametric-oriented histogram equalization (CPOHE), is proposed to effectively yield enhanced results with high contrast and artifact-free texture using the concept of integral image, and further correct the accompanied distortion. As documented in the experimental results, the proposed method provides a high practical value for applied in visual perception, biometric, and tracking/detection applications.

1. Introduction

Nowadays, image enhancement [9] plays an important role in vision-wise applications, for instance, the enhancement of brightness or contrast. These methods are widely-used for either a better visual perception for the human visual system or a higher discernible capability for rear-end analysis. Among these, the latter issue attracts more attentions because of the rises of some popular fields, such as the medical imaging and pattern recognition [17]. These can be attributed to its properties about exploiting textures and luminance normalization. In general, these methods are roughly grouped into global and local categories according to their purposes and considerations. As for the methods in the global category, consistency and balance of the entire enhanced image should be maintained, and normally the noise issue is also considered for presenting pleasant visual quality. Conversely, the local schemes mostly aim at the stability of the local brightness as well as mining more distinguishable details.

Global histogram equalization (GHE) [9] is the most representative global way of contrast enhancement, and typically it is expected to improve images by achieving a uniform distribution of pixel values. First, this method collects the grayscale histogram (called probability density function (pdf)) of the entire image and then adopts the corresponding cumulative distribution function (cdf) as the transformation function. This method can be implemented easily, and it offers high processing efficiency. Yet, it lacks good brightness preservation and visually pleasurable perception. To remedy these issues, some former studies have proposed more effective algorithms to achieve a better performance [3–5,14,24,25,30]. So far a widely acceptable way of coping with the above issues is to separate this entire histogram into multiple sub-histograms, and then

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enhance them individually. For instance, bi-histogram equalization (BBHE) [14] and dualistic sub-image histogram equalization (DSIHE) [30] separated the histogram into two using either the mean or the median value of the given histogram. As a result, these methods apply two sub-histograms, and also limit the room of brightness preservation. Subsequently, some methods such as recursive mean separate histogram equalization (RMSHE) [4] and recursive sub-image histogram equalization (RSIHE) [25] extended the essences of BBHE and DSIHE, respectively, for presenting a better performance. Moreover, multiple histogram equalization (MHE) [24] and Celik-Tjahjadi's method [5] also achieved an improvement through the same concept. Recently, the adoption of wavelet transform is another popular way of enhancing contrast [6,31,32]. Although these wavelet-based methods offer good enhanced results and noise suppression simultaneously, the required transformation and its inverse process also increase the entire computations (4.9 s were needed for a frame of size 256×384 when a Pentium 4 2.4 GHz CPU was adopted). Hence, these methods are widely-used in medical imaging which has a less demand on processing efficiency.

Conversely, to explore more discernible details of images, the local enhancement [20] is considered for each pixel as the local methods, while it also drastically raises its computation requirement. For instance, the region of size 21×21 was used in Sakellaropoulos et al.'s wavelet-based method [26], and an unrealistically high complexity was required (122 s for a frame of size 1400×2300 when performed with Pentium 4 1.5 GHz CPU and 1GB of RAM). For some applications, e.g., intelligent surveillance system, biometric, tracking, and detection, due to the processing efficiency is a rather crucial factor, some specific studies toward computation simplification are motivated. Also, for one of those popular image enhancement topics, the high-dynamic-range imaging (HDR) also demands higher efficiency for the need of batch processing with tons of photos. For instance, Stark [27] proposed an adaptive contrast enhancement method to leave a room for further adjustment to meet the needs of different applications and even a preferred effect. In this method, the concept of the signed power-law and local-mean replacement methods were adopted to derive the required transformation functions, whereas two adjustable parameters, the accumulation function power and the proportion of local-mean, were retained. Moreover, Yu-Bajaj's method [33] employed the isotropic and anisotropic propagations to yield the required maximum, minimum, and average maps for contrast enhancement. Since the propagation information replaces the role of Gaussian filtering [8], its computational complexity is also reduced. Kim et al.'s partially overlapped sub-block histogram equalization (POSHE) [15] utilized the concept of block-wise processing to replace the former pixel-wise strategy. In their method, the pixels in a block use an identical group of cdfs (including neighboring blocks, and the weight of each cdf according to a low-pass filter) to obtain the shared transformation function, and thus the processing efficiency is further improved. Since this method needs lots of computations on filtering, a method called cascaded multistep binomial filtering histogram equalization (CMBFHE) [21] is proposed to utilize a binomial filter with fewer computations to replace the role of the formerly used low-pass filter. Another similar way, termed non-overlapped sub-blocks and local histogram projection based contract enhancement (NOSHP) [22], was also proposed for further simplification. In this method, the proportion of each neighboring block's cdf is adopted. Kimori's method [18] utilizes the rotational morphological processing to enhance images and it combines the enhanced result with the original image for the final output. Lal-Chandra's method [23] achieves a high efficiency method which utilizes both of the modified sigmoid function and the contrast limited adaptive histogram equalization (CLAHE) for contrast enhancement. Ibrahim-Hoo [12] proposed a method, termed local contrast enhancement utilizing bidirectional switching equalization of separated and clipped subhistograms (LCE-BSESCS), for both purposes of higher sharpness and less noise amplification. Although all of the above introduced local methods offer improved contrast or high processing efficiency, the visual perception quality is reduced, causing by some artificial textures, or less discernible details because of the accompanied low contrast. These sacrifices, however, erase the usability on medical imaging and pattern recognition.

In this study, the corrected parametric-oriented histogram equalization (CPOHE) is proposed to produce locally contrast-enhanced results without perceivable artifacts, and achieve a less runtime. In this method, the concept of the integral image is employed to simplify the computations of the required factors. With this strategy, the processing efficiency is not affected by the size of the considered neighborhood. To further enhance the contrast, the concept of classification for the adopted kernel functions and the approximation for yielding more accurate transformation functions are considered.

The remainder of the paper is organized as follows. Section 2 first introduces a simplified prototype of the proposed method. Later on, some modifications and approximations are then elaborated in Section 3. The experimental results are demonstrated in Section 4. Finally, the conclusions are drawn in Section 5.

2. Prototype

2.1. Typical AHE

To have a better understanding of the proposed method, the typical adaptive histogram equalization (AHE) [1] is first introduced. In AHE, each grayscale has an independent transformation function $f(\cdot)$. The relationship between the input image and the enhanced image can be formulated as below,

$$y_{i,j} = f\left(x_{i,j}\right), \quad \text{where}\, x_{i,j} \in \mathbb{Z} \quad \text{and} \quad y_{i,j} \in \mathbb{Z}, \tag{1}$$

where $x_{i,j}$ and $y_{i,j}$ denote the given grayscale and the corresponding contrast enhanced grayscale, respectively. This transformation function is obtained by considering all of the pixels in its neighborhood. As per the thought of traditional HE [9], it suggests that a uniform grayscale distribution is able to provide the best contrast, and thus the cdf of the grayscale