**LETTER**

Gaussian Kernel-Based Multi-Histogram Equalization*

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**SUMMARY**

Histogram equalization is the most popular method for image enhancement. However, it has some drawbacks: i) it causes undesirable artifacts and ii) it can degrade the visual quality. To overcome the drawbacks, in this letter, multi-histogram equalization on smoothed histogram using a Gaussian kernel is proposed. To demonstrate the effectiveness, the method is tested on several images and compared with conventional methods.

**key words:** multi-histogram equalization, Gaussian kernel

1. Introduction

Image enhancement is a technique for improving the visibility and details of an image. Among the many different types of image enhancement methods that have been developed, histogram equalization (HE) [11]–[9] is the most popular because of its simplicity and effectiveness. The basic idea behind HE is to remap the gray levels of an image by using a cumulative density function (CDF). Despite its overall effectiveness, HE does have some drawbacks. It can significantly change the brightness of an image, for example, and it sometimes causes undesirable artifacts [2]–[9]. It can also degrade the visual quality of an image [3].

Various methods have been proposed to address these drawbacks [2]–[9]. The conventional methods can be categorized into bi-histogram methods and multi-histogram methods. Bi-histogram methods include brightness preserving bi-histogram equalization (BBHE) [2], dualistic sub-image histogram equalization (DSIHE) [3], minimum mean brightness error bi-histogram equalization (MMBEBHE) [4], and recursive mean-separate histogram equalization (RMSHE) [5], which is the generalization of BBHE. Multi-histogram methods include RMSHE [6], recursive sub-image histogram equalization (RSIHE) [7], and others [8], [9]. Each type of method has its characteristic strengths and weaknesses. Bi-histogram methods may not generate output images that look as natural as those from multi-histogram methods, while multi-histogram methods may not generate output images that are as enhanced as those from the bi-histogram methods. This is particularly true for RMSHE and RSIHE, where the enhancement degree is degraded as the parameter $r$ is increased.

Therefore, in this letter, we propose a Gaussian kernel-based multi-histogram equalization (GKMHE) method that is possible to perform the enhanced output image with maintenance of the visual quality of input image. Gaussian kernel is used to smooth histogram, and multi-histogram equalization is performed on the smoothed histogram. The reason to choose Gaussian kernel as smoothing function is that the kernel has the properties of smoothing intensity from a maximum center, radial symmetry, and distribution tail that is nonzero for all distances from the center [10], [11]. Based on the properties, Gaussian kernel provides gentler smoothing and preserves better peak of histogram than others. In order to demonstrate the effectiveness of the proposed method, we present experimental results and absolute mean-brightness error (AMBE) [4], [5], [9] measures of the proposed method and the conventional methods.

2. Gaussian Kernel-Based Multi-Histogram Equalization

2.1 Gaussian Kernel and Smoothed Histogram

Let $X = \{x_1, \ldots, x_n\}$ be a data set in an $s$-dimensional Euclidean space $R^s$, and $K$ be a kernel. The kernel density estimate at a point $x$ is given by:

$$\hat{f}_K(x) = \frac{1}{n} \sum_{i=1}^{n} K(x - x_i)$$

(1)

And the Gaussian kernel is defined as follows [12], [13]:

$$G^p(x) = \left[ \exp \left( -\|x - x_i\|^2 / \beta \right) \right]^p$$

(2)

where $\beta$ and $p$ are the normalization and smoothing parameters, respectively, and $\| \|$ denotes Euclidean norm. From Eqs. (1) and (2), the Gaussian smoothed histogram is defined as follows:

$$h^p(g) = \frac{1}{N} \sum_{z=0}^{L-1} h(z) \left[ \exp \left( -\|g - z\|^2 / \beta \right) \right]^p$$

(3)

where $g$ and $z$ represent the gray levels $[0, L-1]$, $N$ is the total number of pixels in an image, and $h(z)$ is occurrence frequency of the gray level $z$. In Eq. (3), in this letter, the normalization parameter $\beta$ is set as variance:

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\[
\beta = \frac{1}{N} \sum_{z=0}^{L-1} \|z - \bar{z}\|^2 h(z), \bar{z} = \frac{1}{N} \sum_{z=0}^{L-1} zh(z) \quad (4)
\]

Moreover, the smoothing parameter \( p \) influences on the amount of smoothing as discussed in [12]. As shown in Fig. 1, different \( p \) corresponds to different shapes of the smoothed histogram.

### 2.2 Selection of Threshold Values and Gaussian Kernel Parameter

There are many kinds of threshold selection method based on histogram [14]–[17]. Among these, Otsu’s method [15] is one of the most popular and powerful methods, but this technique takes too much time to select multi-threshold values. To overcome the problem, Cao et al. [16] developed a fast automatic multilevel thresholding method based on maximum entropy theorem. In this letter, we apply it to the selection of optimal multi-threshold values.

**Step 1:** Equalize each partition of the smoothed histogram.

**Step 2:** Select the optimal kernel parameter for the smoothed histogram by using Eq. (6).

**Step 3:** Select the optimal threshold values by Eqs. (5) and (7).

**Step 4:** Map each partition of the smoothed histogram, which is divided into a new range with the threshold values.

**Step 5:** Equalize each partition of the smoothed histogram independently.

### 3. Experimental Results and Remarks

To demonstrate the performance of the proposed approach, we applied several conventional methods (HE, BBHE, DSHIE, MMBEHBE, and RMSHE) as well as the proposed method (GKMHE) to the images shown in Fig. 2. In Table 1, we display the selected kernel parameter and the number of partitions according to images. The enhanced results and AMBE are shown in Figs. 3, 4, 5 and Table 2.

Although the proposed method is not always the best at preserving the brightness of the input image, as shown in Table 2, we can see from Figs. 3 and 4 that the proposed...
method produces a clear output images while the others create undesired artifacts. In other words, the proposed method generated more naturally and clearly enhanced images than the other methods. In particular, from Fig. 5 that is enlarged images of background of Fig. 4, the output images using the conventional methods have noisy pixels while the output image using the proposed method has clear background without noise.

4. Conclusion

We have proposed a multi-histogram equalization method based on a smoothed histogram with a Gaussian kernel. With experimental results and AMBE tests on several images, we have shown that the proposed method creates images with quality that is similar to or better than images from conventional methods.

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References


