A Uniformity-Approximated Histogram Equalization Algorithm for Image Enhancement

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SUMMARY In this letter, we propose a novel Uniformity-Approximated Histogram Equalization (UAHE) algorithm to enhance the image as well as to preserve the image features. First, the UAHE algorithm generates the image histogram and computes the average value of all bins as the histogram threshold. In order to approach the uniform histogram, the bins of image histograms greater than the above threshold are clpped, and the subtracted counts are averaged and uniformly assigned to the remaining bins lower than the threshold. The approximated uniform histogram is then applied to generate the intensity transformation function for image contrast enhancement. Experimental results show that our algorithm achieves the maximum entropy as well as the feature similarity values for image contrast enhancement.

key words: image enhancement, histogram equalization, entropy, feature similarity

1. Introduction

Histogram Equalization (HE) is a well-known algorithm that is straightforward and efficient for image contrast enhancement. The focus of the HE is to arrange the original distribution of gray-levels as dynamic ones to enhance the image contrast indirectly. However, the HE method usually misses some gray-levels to cause the over-enhancement. Hence, the Flat HE (FHE) [1] uses the iterative mapping function to adjust each level for generating the fully uniform output histograms, but it is inapplicable to the feature preservation and consumes high computation cost.

In order to overcome the above weakness, the Auto-Weighted and Mean-separated HE (AWMHE) algorithm is proposed using the histogram division technique [2]. The AWMHE algorithm calculates the weighted means using the cumulative distribution as the thresholds of sub-histograms at each iteration. The histogram division is iteratively performed until the maximum threshold becomes the maximum gray level, and each sub-histogram is equalized independently.

The Exposure based Sub-Image HE (ESIHE) algorithm presents another way to divide the histogram image using the image exposure value [3]. It also computes the average bin value of the image histogram to clip its probability density in order to reduce the missed gray-level counts after enhancing the image.

Although equalizing the sub-histograms can reduce the over-enhancement of the whole image, the texture, edges, and other features in the local area may be distorted since the applied image histogram for transformation function is usually not uniform. To preserve the local image features, we then propose a Uniformity-Approximated HE (UAHE) algorithm in this letter.

2. UAHE Algorithm

Given an input image $I$. The image histogram of $I$ is denoted by $H$, and $H(l)$ is the various pixel count of each bin in $H$. According to [3], histogram clipping is applicable to preventing over enhancement by HE. The idea is to clip the large pixel counts of bins greater than the pre-defined threshold, after which the clipped histogram is then applied to compute the transformation function for enhancing the input image.

In this letter, we not only generalize this idea but also give an extension based on the maximum entropy approximation. In general, average information content is measured by entropy. For a 8-bit image, the maximum entropy can be obtained when the probability density of each bin all equals $1/256$. Hence, we compute the histogram threshold defined as follows:

$$T_H = \frac{1}{l_{max} - l_{min}} \sum_{l_{min}}^{l_{max}} H(l),$$

(1)

where $l_{min}$ and $l_{max}$ denote the minimum gray level and maximum gray level of the input image.

In contrast to the ESIHE that only clips the large counts of bins, we further compensate other small counts of bins in order to approximate the uniform histogram for entropy maximization. For each bin $l$, we compute the subtraction value and the corresponding count denoted by

$$S(l) = \begin{cases} H(l) - T_H, & \text{if } H(l) > T_H, \\ 0, & \text{otherwise}, \end{cases}$$

(2)

and

$$C(l) = \begin{cases} 0, & \text{if } H(l) > T_H, \\ 1, & \text{otherwise}. \end{cases}$$

(3)

Note that $l$ ranges between $l_{min}$ and $l_{max}$. The improved histogram clipping of our UAHE is then expressed as follows:

$$H'(l) = \begin{cases} T_H, & \text{if } H(l) > T_H, \\ H(l) + G, & \text{otherwise}, \end{cases}$$

(4)
where $G$ is the gain value computed by
\[
G = \frac{\sum_{l=l_{\text{min}}}^{l_{\text{max}}} S(l)}{\sum_{l=l_{\text{min}}}^{l_{\text{max}}} C(l)}.
\] (5)

The normalized histogram is then calculated as follows:
\[
H_n(l) = \frac{H'(l)}{\sum_{l=l_{\text{min}}}^{l_{\text{max}}} H'(l)}.
\] (6)

The transformation table is then computed by
\[
T(l) = \left(2^8 \sum_{p=l_{\text{min}}}^{l} H_n(p) \right) - 1.
\] (7)

After each pixel of the input image is mapped using the above table, the contrast enhancement result is then generated.

3. Experimental Results

In our experiments, we use four test images named clock, Einstein, tank, and woman images. We compare our UAHE algorithm to the AWMHE, ESIHE, and FHE algorithms under the visual inspection as well as quantitative evaluation.

Figure 1 shows the contrast enhancement results by each method. It indicates that the over enhancement is caused by the AWMHE, FHE, and ESIHE methods. In contrast, the UAHE algorithm effectively overcomes the over enhancement due to the use of uniformity-approximated histogram.

4. Conclusions

This letter has proposed a new HE-based method using the concept of maximum entropy approximation. Our method simply clips the histogram using the adaptive threshold to approximate the uniform one, so the constructed transformation table of the improved histogram is applicable to good control of over enhancement. The quantitative measures of the UAHE algorithm verifies that it outperforms other state-of-the-art HE-based algorithms in terms of the balance between contrast enhancement and feature preservation.

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