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Image contrast enhancement using fuzzy clustering with adaptive cluster parameter and sub-histogram equalization

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A B S T R A C T

Histogram equalization is an effective technique to boost image quality and contrast enhancement. However, in some cases the increase in image contrast by traditional histogram equalization exceeds the desired amount Which damages the image properties and wanes its natural look. Histogram division and performing a separate equalization for each sub-histogram is one of the presented solutions. The dividing method and determining the number of sub-histograms are the main problems directly affecting the output image quality. In this study, a method is introduced for automatic determination of the number of sub-histograms and density based histogram division leading to appropriate output with no need for parameter setting. Each main peak is in a separate section. Image contrast is increased with no loss of image specifications through determining the number of sub-histograms based on the number of main peaks. The introduced histogram equalization approach consists of three stages. The first stage, using histogram analysis, produces an automated estimate of number of clusters for image brightness levels. The second, clusters the image brightness levels, and using the provided transfer function, the final stage includes contrast enhancement for each individual cluster separately. The results of the proposed approach demonstrate not only clearer details along with a boost in contrast, but also noticeably more natural appearance in the images. 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Increasing the visual quality of the image and making details more visible is the purpose of image contrast enhancement. Contrast enhancement is an effective phase in image processing and computer vision applications. It is used as a pre-process for speech recognition. Moreover, the following applications rely on image contrast enhancement: remote examination [1–4], digital recording [5], security surveillance systems [6], underwater vision enhancement [7], and face recognition [8]. Also image contrast enhancement has several functions in machine learning which include video applications [9], motion detection [10,11], and object detection/classification [12].

Contrast enhancement is a subset of a concept called histogram modification, performed via applying a transfer function on histogram and then expanding it [13]. The transfer function can be a local function or a global one. The former, influences only a specific scope of the histogram while the latter is concerned with all histogram values [14–17].

Histogram equalization is a highly renowned image contrast enhancement method benefiting from a global transfer function. As one of the most basic image contrast enhancement methods, it uses a transfer function based on the accumulated distribution of the complete image. Each value maps the gray levels of the image to a new value. Average gray level (brightness level) is equalized using the histogram equalization method, regardless of the main image, which is always equal to the mean brightness level, i.e. the so-called approach, due to the great deal of change implied on brightness values, is not suitable in cases where the brightness or the average brightness of the image remain the same [18]. A sample image and the image result of performing HE method is depicted in Fig. 1.

Histogram division is a solution for HE issue in [19]; it undertakes the histogram equalization method on two sub-images (sub-histograms) individually. Based on the mean value, the two sub-images are obtained. The method preserves the average brightness of the input image and performs only a single segmentation on the input image histogram. Therefore, after histogram equalization, along with distortions caused by noise, highly enhanced areas remain evident across the image.

In 2003, Using a recursive repetition of BBHE, Chen invented the RMSHE method [20]. At every stage of this method, with re-

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1051-2004/

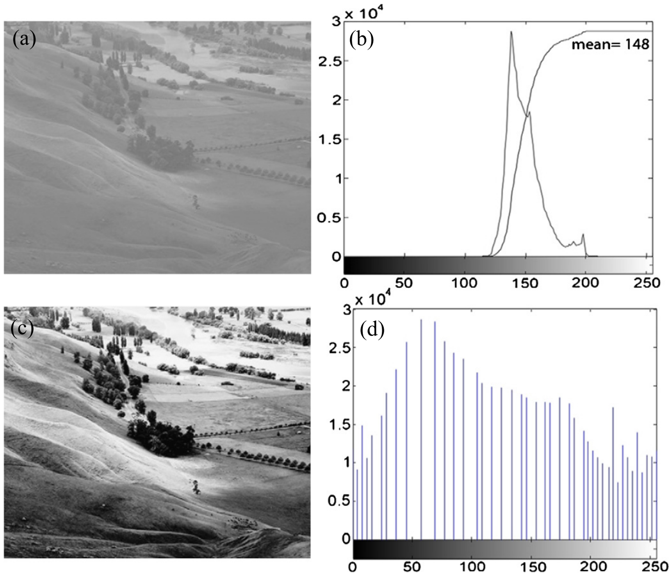

Fig. 1. Histogram equalization. (a) Original image. (b) Histogram of original image and corresponding CDF (Cumulative Distribution Function). (c) Equalized image. (d) Histogram of equalized image.

gard to the average of the image at the current stage, the histogram is divided into two histograms. The same operation happens in 'r' iterations, and the value of r is indicated by the user. Thus, the image histogram is divided into 2^r parts, each subject to histogram equalization individually as in the BBHE method. The method will suffer from same drawbacks as with BBHE, having a small r value. Greater r values provide the conditions to maintain the image average, while selecting a great value for r results in no considerable changes between the histograms of the input image and the output image, leaving us with a non-enhanced image.

Wang proposed a new method called BPHEME in 2005 [21]. Using this method, applying different approaches, a histogram with the maximum possible entropy is obtained. Then, the main image histogram is converted into a histogram with maximum entropy, applying the histogram modification method.

In 2007, the MWCVMHE method was presented [22] to overcome the aforementioned problems. The method works by dividing the image into sub-images and applying the classic histogram equalization method on each sub-image, where the number of sub-images is indicated by a cost function. However, in some cases, the method gives a wavering enhancement in order to preserve the natural look and the mean value of the output image.

The method of Huang presented in 2013 divides the histogram of the image into several parts in a recursive way, applying the brightness levels' mean and deviation values. Then, every segment of the histogram is equalized using accumulated probability distribution function [23].

In [24], the bi-histogram equalization plateau limit (BHEPL) is proposed to control the BBHE enhancement rate. BBHE applies higher stretching process to the contrast of high histogram regions and compresses the contrast of low histogram regions, possibly causing intensity saturation as the intensities are squeezed in the low histogram regions. A clipping process is applied to each sub-histogram of BBHE to deal with the intensity saturation problem to control the enhancement rate through setting the plateau limit as the average number of intensity occurrence. If the bins for any intensity exceed the plateau limit, the bins will be replaced by the plateau limit level; otherwise, they will remain the same as original bins of the input histogram. Finally, the HE is implemented to the clipped sub-histograms.

Huang proposed a combined approach [25], composed of gamma correction and the traditional histogram equalization, called Adaptive Gamma Correction with Weighting Distribution (AGCWD). To overcome the frequently witnessed constraints when working with common contrast enhancement methods, this approach tries to attain a balance between low computational costs and high visual quality. It uses CDF and a normalized gamma function to change the transform curve without missing histogram-related information. Hence, lower values for the gamma parameter causes higher levels of equalization.

Celik [26] estimated gray level distribution in the image to obtain superior histogram partitioning and thus an improved contrast enhancement. Hence, GMM is employed to fit Gaussian models with image histogram, so image brightness levels are estimated. Afterwards, the intersections between Gaussian models indicate histogram partitions. An agreeable number of distributions in the histogram guarantees agreeable output, since the method conducts partitioning based on data distribution. The great challenge is choosing the right number of Gaussian models. Parameter adjustment in which an appropriate enhanced image is produced is a crucial challenge for most contrast enhancement methods.

In [27], a generalized parameter adjustment-independent algorithm was presented to obtain an image with dynamic range area. The algorithm uses a corrected histogram to transfer brightness levels.

Gu used saliency preserving to increase image contrast without dealing with the artifacts problem [28]. The proposed framework includes histogram equalization and its relevant visual pleasing conducted by sigmoid function. Finally, this method exploits a quality determination measure based upon saliency preserving to automatically select parameters. In [29], a method was proposed to avoid over enhancement and noise addition, improving the contrast of an image. The method is a combination of Contrast Limit Adaptive Histogram Equalization (CLAHE) and Discreet Wavelet Transform (DWT), which includes three stages. First, high frequencies of an image and its low counterparts are decomposed by DWT. Image frequency coefficients are equalized by CLAHE, while leaving image high frequency with no alteration. Eventually, reverse DWT is employed to reconstruct the image. The last step contains a weighted factor to obtain an average from the original and the enhanced image, to control possible over enhancement.

Huang developed AGHE to deal with the problem of available brightness saturation, arising when working with HE method [30]. Brightness saturation problem is seen in areas of an image in which the corresponding histogram is narrow, which causes constant alterations in the transform function, resulting in brightness saturation. Therefore, AGHE extracts the transform function not from brightness level histograms, but from that of image gradient.

Metaheuristics methods are novel in contrast enhancement; Genetic Algorithm (GA), Artificial Bee Colony (ABC), and Ant Colony Optimization (ACO) are guided random searches to find an optimum solution in large search spaces (because of difficulties of classic methods in large search spaces). A method was presented in [31] for contrast enhancement which creates the transfer function based on evolutionary algorithms. Using the artificial bee colony algorithm, this method changes the transfer function in each algorithm and tries to achieve the best transfer function by a fitness function according to contrast evaluation. Pourya Hoseini proposed a hybrid algorithm including Genetic Algorithm (GA), Ant Colony Optimization (ACO), and Simulated Annealing (SA) metaheuristics to increase the images contrast [32]. Ant colony optimization is employed to generate the transfer functions which map the input intensities to the output intensities. Simulated annealing as a local search method is utilized to alter the transfer functions produced by ant colony optimization. Genetic algorithm is responsible for evolutionary process of ants' characteristics.