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A fast and efficient color image enhancement method based on fuzzy-logic and histogram

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ABSTRACT

A new fuzzy logic and histogram based algorithm for enhancing low contrast color images has been proposed here. The method is computationally fast compared to conventional and other advanced enhancement techniques. It is based on two important parameters *M* and *K*, where *M* is the average intensity value of the image, calculated from the histogram and *K* is the contrast intensification parameter. The given RGB image is converted into HSV color space to preserve the chromatic information contained in the original image. To enhance the image, only the V component is stretched under the control of the parameters *M* and *K*. The proposed method has been compared with conventional contrast enhancement techniques as well as with advanced algorithms. All the above techniques were based on the principle of transforming the skewed histogram of the original image into a uniform histogram. The performance of the different contrast enhancement algorithms are evaluated based on the visual quality, Tenengrad, CII and the computational time. The inter comparison of different techniques was carried out on different low contrast color images. Based on the performance analysis, we advocate that our proposed Fuzzy Logic method is well suited for contrast enhancement of low contrast color images.

1. Introduction

Contrast enhancement enhances the apparent visual quality of an image as well as the specific image features for further processing and analysis by a computer vision system [1]. For segmentation and identification of objects and features in a scene, the information content of the image has to be enhanced for better performance. Although, the techniques of contrast enhancement perform quite well with images having a uniform spatial distribution of gray values, difficulties arise when the background has a non uniform distribution of brightness [1]. Low contrast images with weak edges pose challenges in the fields of computer vision and pattern recognition. A fast and efficient fuzzy based automatic contrast enhancement of low contrast color images has been proposed here, which enables improvement of visual quality of image as well as aid in extraction of the spatial features present in the image. The method is computationally fast compared to other advanced enhancement algorithms such as Gray Level Grouping (GLG) [11] and fuzzy based enhancement technique of [13]. The method is mainly based on two important parameters, one the average intensity value of the image *M* and the other a contrast intensification parameter *K*. The proposed method is applied to the HSV color space so that only the V component is stretched by preserving the chromatic information (H and S).

2. Contrast enhancement techniques

The real world applications of automated image contrast enhancement techniques are many and encompass varied fields like medical imaging, geophysical prospecting, seismic exploration, astronomy, camera and video processing, aerial and ocean imaging, sensors and instrumentation, optics, and surveillance. Conventional techniques for contrast enhancement include gray-level transformation based techniques (*viz.*, logarithm transformation, power-law transformation, piecewise-linear transformation, *etc.*) and histogram based processing techniques (*viz.*, histogram equalization (HE), histogram specification, *etc.* [1]). The most popular method is histogram equalization, which is based on the assumption that a uniformly distributed grayscale histogram will have the best visual contrast. Other advanced histogram based enhancement methods include bi-histogram equalization (BHE), block-overlapped histogram equalization, multi-scale adaptive histogram equalization, shape preserving local histogram

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modification, *etc.* [2–10]. Conventional contrast enhancement techniques have an inherent inability for automation due to the necessity to select specific parameters for enhancement. Other drawbacks include the washed out effect, inability to preserve edges, non-preservation of brightness and the inability to discern localized intensity changes. Recent studies [11–14] stress on the importance and necessity of having automatic methods for contrast enhancement and suggest that the GLG and Fuzzy Logic based methods are better suited for automatic contrast enhancement of images.

The basic objective of Gray Level Grouping (GLG) [11,12,22,23] is to achieve a uniform histogram for a low contrast color image. GLG utilizes the grayscale in a more controlled and efficient manner, thus spreading the components of histogram by grouping the components into a proper number of gray-level bins according to their amplitudes ensuring a reduction in the number of gray bins. This will lead to the redistribution of the histogram components in a set of gray-level bins whose amplitudes are close to each other. Conventional histogram equalization results in under or over contrast image since it leaves too much empty space on the grayscale. In GLG, histogram components in different segments of the grayscale can be grouped using different criteria, so they can be redistributed differently over the grayscale to meet specific purposes, *e.g.*, certain applications may require different parts of the histogram to be enhanced to different extents. The drawback of GLG is that it is not computationally efficient compared to fuzzy-based methods. The quantitative analysis shows that fuzzy-based methods are superior to GLG.

Fuzzy-logic is being efficiently utilized in different areas of image processing. In recent years, fuzzy based algorithms for image enhancement has been developed with better performance compared to conventional and other advanced techniques like GLG. Fuzzy image processing consists of mainly three stages: image fuzzification, modification of membership values, and, if necessary, image defuzzification. The main power of fuzzy image processing is in the middle step (modification of membership values). After the image data are transformed from gray-level domain to the fuzzy membership domain (fuzzification), appropriate fuzzy techniques modify the membership values. This can be a fuzzy clustering, a fuzzy rule-based approach, a fuzzy integration approach and so on. In fuzzy based image enhancement algorithms histogram is used as the basis for fuzzy modeling of images. Two major contributions in the field of image enhancement using the fuzzy framework have been established in recent years. The first contribution deals with basic fuzzy rules for image enhancement [15–17], where in a set of neighborhood pixels forms the antecedent and the consequent clauses that serve as the fuzzy rule for the pixel to be enhanced. The second contribution relates to a rule-based smoothing [18] in which different filter classes are devised on the basis of compatibility with the neighborhood. Recently Hanmandlu et al. [21] has proposed a fuzzy based method in which entropy measure is used as the basic criterion for contrast enhancement.

In the fuzzy method [19] gray tone is modeled into a fuzzy set using a membership function. Here the image is considered as an array of fuzzy singletons having a membership value that denotes the degree of some image property in the range. Applying an intensification operator globally modifies the membership function. Li and Yang [20] have demonstrated an efficient way of contrast enhancement based on the fuzzy relaxation technique with improved speed and quality. Different orders of fuzzy membership functions were tried out by various researchers in order to improve the speed and quality of contrast enhancement based on the fuzzy logic method. Recently, Hanmandlu et al. [21] proposed a new intensification operator, NINT, which is a parametric sigmoid function for the modification of the Gaussian type of membership. The method is based on the optimization of entropy by a parameter involved in the intensification operator which is suitable for gray level images. Hanmandlu and Jha [13] proposed a Gaussian membership function to fuzzify the image information in spatial domain by introducing a global contrast intensification operator which contains three parameters, t, the intensification parameter, f_h, the fuzzifier and μ_c the cross over point – for enhancement of color images. The method is an iterative procedure based on modified univariate algorithm which uses partial differentiation. The drawback of this method is that the procedure is complex and computationally takes more time, though it is better than GLG.

3. Proposed fuzzy-based method

The proposed fuzzy enhancement method uses *HSV* color space where only the V component is stretched by preserving the chromatic information such as Hue (H) and Saturation (S). The method is meant exclusively for enhancing low contrast and low bright color images. Stretching of V component is performed under the control of the enhancement parameters M and K. This stretching will transform the current intensity value x to the enhanced intensity value x_e.

The first step in the proposed method is to convert the given *RGB* image of size $P \times Q$ into *HSV* and then calculate the histogram $h(x)$ where $x \in V$. $h(x)$ indicates the number of pixels in the image with intensity value x. Proposed method uses two intensification parameters M and K, which controls the degree at which the intensity value x has to be intensified. The control parameter M, the average intensity value of the image, can be calculated from the histogram as follows:

$$M = \frac{\Sigma_X X h(X)}{\Sigma_X h(X)} \tag{1}$$

The parameter M divides the histogram $h(x)$ into two classes. The first class C_1 contains pixels values in the range $[0, M-1]$ and the second class C_2 in the range $[M, 255]$. The stretching of V component is performed based on two fuzzy membership values μ_{D1} and μ_{D2}, calculated for C_1 and C_2 class of pixels respectively. Parameter M has a significant role in the computation of fuzzy membership values, μ_{D1} and μ_{D2}.

Enhancement parameter K decides the stretching intensity to compute the enhanced intensity values x_e for the two classes C_1 and C_2. Parameter K decides the stretching point to which the intensity values x should be stretched based on the membership values μ_{D1} and μ_{D2}. The value for K can be computed empirically according to what extent the stretching is required. From the experimental analysis, we fixed the value 128 for K, which gives better results for the low contrast and low bright color images.

The fuzzy membership value μ_{D1} for class C_1 is based on the concept of how far the intensity value x is from the parameter M. The fuzzy rule for class C_1 can be represented as follows:

If the difference between x and M is LARGE then the intensity of stretching should be SMALL.

The above rule indicates that the pixels values closer to M will be extended higher whereas values farther from M will be extended lesser. Pixel values in between will be extended proportionately. To implement the above fuzzy rule the following mathematical representation can be used:

$$\mu_{D1}(X) = \frac{1-((M-X)}{M} \tag{2}$$

where $x \in C_1$. Once the membership value for x is obtained, the contrast enhanced or intensified value x_e for class C_1 can be computed as follows:

$$X_e = X + \mu_{D1}(X)K \tag{3}$$