Piecewise Fuzzification of the Intensity and Texture Information for Color Image Enhancement

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Abstract

In this paper, we propose a piecewise fuzzification approach to contrast enhancement of color images, which is one of the most important issues in image processing, pattern recognition and computer vision. The proposed algorithm utilizes fuzzy logic to make the edges of the objects in an image much clear. Experimental results demonstrate that the proposed approach is very effective and efficient in contrast enhancement of color images.

Keywords: Fuzzy logic, Color image, Enhancement, Entropy

1. Introduction

Contrast enhancement is one of the most important topics in image processing, pattern recognition and computer vision, which can sharpen the edges of object and attain more information for further processing of the enhanced image. Contrast enhancement methods can be separated into two categories: indirect methods and direct methods [1]. The direct methods are based on information of space domain of an image; the indirect methods are based on that of frequency domain.

Because the edges of the objects in an image are quite blur, fuzzy technologies were applied to perform contrast enhancement recently [2]. Fuzzy logic was also introduced to contrast enhancement of color image [3]. However, [3] just used the global information, and thus the algorithm suffered noise amplification and had under-enhancement and over-enhancement problems.

In this paper, we introduce a piecewise fuzzification approach and apply it to contrast enhancement of color images using both global and local information. Based on a good selection of the parameters, under-enhancement and over-enhancement problems are solved in our experimental results. Moreover, selecting suitable color space is also considered. RGB color space is not suitable for color image enhancement [4]. We have studied other color spaces, such as HSI, HSV and CIE [5]. According to our experiments, HSV has much better performance than other color spaces. Therefore, only HSV color space is discussed in the paper, but the method is able to apply to other color spaces.

Section 2 gives a brief overview of fuzzy logic used in the paper. Section 3 presents the proposed algorithm. Section 4 discusses the experiments and results. Conclusions are drawn in section 5.

2. Fuzzy Logic

2.1. S-function

The standard S-function is a commonly used method for fuzzification [6].

$$\mu(x) = S(x;a,b;c) = \begin{cases} 0 & x \le a \\ \dfrac{(x-a)^2}{(b-a)(c-a)} & a < x \le b \\ 1-\dfrac{(x-c)^2}{(c-b)(c-a)} & b < x < c \\ 1 & x \ge c \end{cases} \quad (1)$$

where the fuzzy value, $\mu(x)$, represents x's membership, a, b, and c are the parameters that decide the shape of the S-function.

2.2. Enhancement operator

A powerful enhancement function was proposed [1], and its variation is used here as an enhancement operator.

$$x_{adj} = \begin{cases} (x_{nor})^P \cdot T^{1-P} & 0 \le x_{nor} \le T \\ 1-(1-x_{nor})^P \cdot (1-T)^{1-P} & T < x_{nor} \le 1 \end{cases} \quad (2)$$

where x_{nor} is the normalized variable, $0 \le x_{nor} \le 1$, T is a threshold, that is, the values greater than T are enhanced, and others are de-enhanced, and P is a variable parameter.

2.3. Entropy

The entropy is a very important concept in an information system, which can be used to measure the information capability. The entropy of an image X was defined as follows [7],

$$H(X) = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} S_n(x) \quad (7)$$

where $S_n(\cdot)$ is a Shannon function, which can be calculated as $S_n(x) = -x \log_2 x - (1-x)\log_2(1-x)$, M and N are the width and the height of the image X, and x is the normalized variable same as the one in Eq. 2. Parameters need to be adjusted in order to satisfy the maximum fuzzy entropy principle.

3. Proposed Method

3.1. The algorithm

There are four major steps in the proposed algorithm:

- Convert RGB image to HSV domain;
- Adjust coefficients in S and V by using histogram enhancement and/or texture enhancement based on the nature of the image (we will discuss this in details later);
- Convert the enhanced HSV image back to RGB domain.

  The flowchart of the algorithm is shown in Fig. 1.

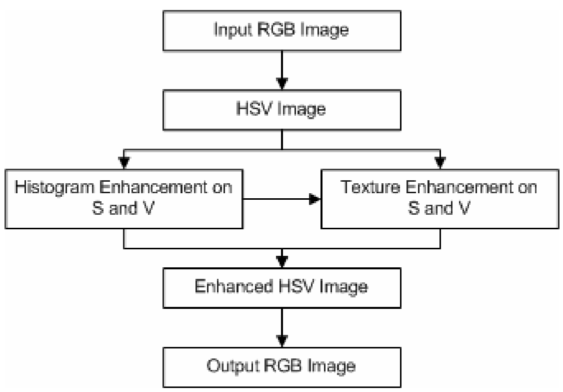


Fig. 1: The proposed algorithm.

3.2. Histogram enhancement

For the coefficients in each domain of S and V, the following steps are applied:

- Normalize the values to [0, 1]

$$x_{nor} = \frac{x_{org} - x_{min}}{x_{max} - x_{min}} \quad (8)$$

where x_{min} is the minimum value of the image in that domain and x_{max} is the maximum value of image in that domain, x_{org} and x_{nor} are the original value and normalized value, respectively;

- Plot the histogram at level 256;
- Smooth the histogram using an m-point moving average in order to find the locations of the major maxima;
  1. initially, Let N=256;
  2. Count the number of maxima as n in the histogram;
  3. Exit this loop if $N=n$, otherwise do step 4;
  4. Let $N=n$;
  5. Compute the average distance between maxima using the following formula,

$$\overline{m} = \frac{256}{N} \quad (9)$$

  6. Smooth the histogram using an $\overline{m}$ -point moving average, and then go to step 1.
- The entire histogram is divided into N pieces. m_i ($i=1,2,\ldots,N$) is the corresponding location x_{nor} of the i[th] maximum values. Initially, let $a=0$ and $b=m_i$, do the following steps for each piece i,
  1. If $i \neq N$, choose m' between m_i and m_{i+1}, and then piecewise fuzzify the adjacent two pieces and enhance them to maximize the entropy of the whole image, here $c = m'$ for the i[th] piece and $a = m'$ for the i+1[th] piece. The formula below is derived from Eq. 1 and Eq. 2 for values in [a c].

$$\mu(x) = \begin{cases} a + (x-a)^{2P}(b-a)^{1-2P} & a \le x \le b \\ c - (c-x)^{2P}(c-b)^{1-2P} & b < x \le c \end{cases} \quad (10)$$

  2. If $i = N$, let $c = 1$. Eq. 10 is also employed to fuzzify and enhance this piece.
- If the entropy of the enhanced image is greater than that of the original image, the original image is replaced by the enhanced image.
- Restore the original domain by the below formula,

$$x_{org} = x_{\min} + x_{nor} \cdot (x_{\max} - x_{\min}) \quad (11)$$

The flowchart of the histogram enhancement is shown in Fig. 2.

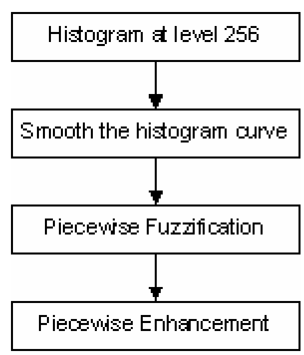


Fig. 2: Histogram enhancement.

3.3. Texture enhancement

The basic idea of the texture enhancement is similar to that of the histogram enhancement, that is, the histogram enhancement is applied in local windows:

- Define a local window around every point (x, y), 7×7 is the most suitable window size in our experiments;
- Normalize values same as the process of the histogram enhancement;
- Apply a different smooth method from the one used in the histogram enhancement, because the volume of local data is too small;
  1. Let level L=256;
  2. Plot a histogram at level L;
  3. Count the number of maxima as N in the histogram;
  4. Exit this loop if $N \leq 2$, otherwise do step 5;
  5. Let $L/2 \rightarrow L$, go to step 2;
- Apply piecewise fuzzification and enhancement described in the histogram enhancement;
- Update the value of the center point (x, y) if the entropy of the image is greater than that of the original image;
- Restore to the original value domain.

The flowchart of the texture enhancement is shown in Fig. 3.

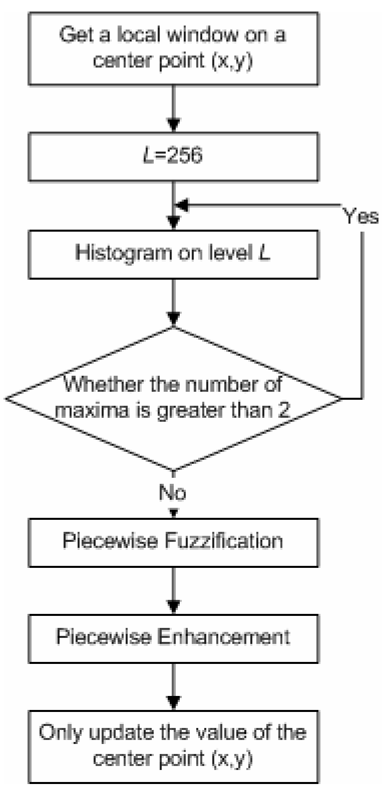
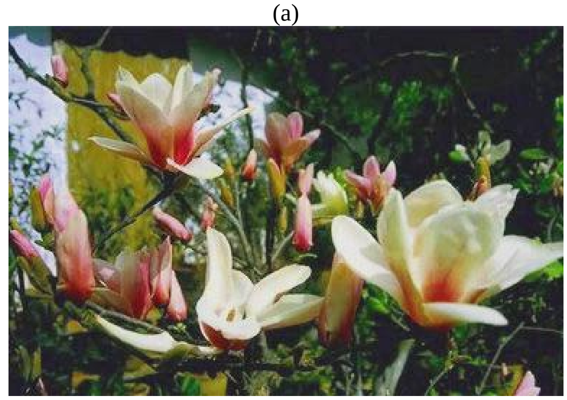
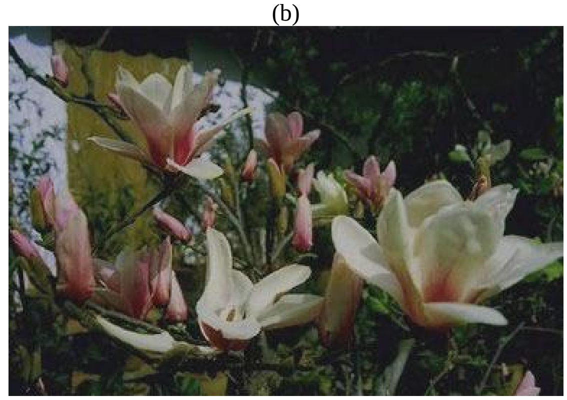


Fig. 3: Texture enhancement.

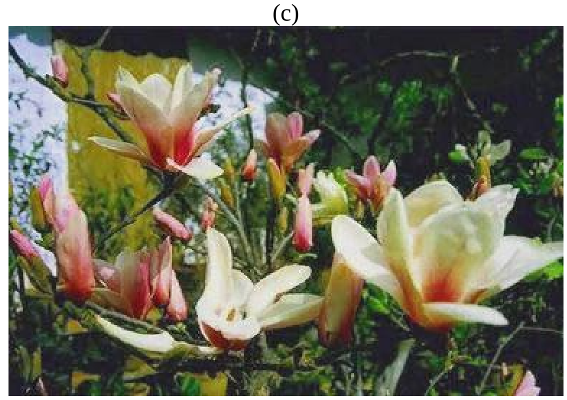
(a)



(b)



(c)



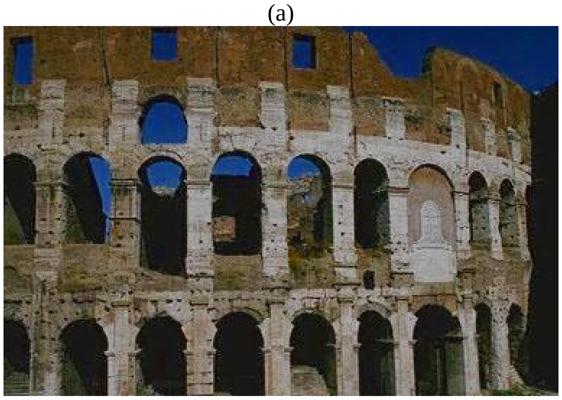
(d)

Fig. 4: (a) The original image; (b) The image enhanced by the histogram enhancement; (c) The image enhanced by the texture enhancement; (d) The image enhanced by both the histogram enhancement and texture enhancement.

4. Experimental Results and Discussions

Fig. 4(a) is the original image which is a low contrast and vague image. Fig. 4(b) is the result enhanced by the histogram enhancement with *P*=1. Obviously, image (b) is much better than image (a), and the contrast around flowers is clearer, and branches and leaves in dark become more distinct. Fig. 4(c) is the results enhanced by the texture enhancement with *P*=1. The texture is more vivid and the objects are easy to recognize in image (c), but the image is still dark. Thus, Fig. 4(d) is the result enhanced by the texture enhancement after the histogram enhancement. Comparing image (b) and image (d), the texture in image (d) is much clearer than that in image (b). In summary, image (d) combines the advantages of both the histogram enhancement and texture enhancement. As we stated in Fig. 1, both the histogram enhancement and texture enhancement can perform contrast enhancement individually, but the combination of the two algorithms can achieve a better result.

(a)



(b)

Fig. 5: (a) The original image; (b) The image enhanced by both the histogram enhancement and texture enhancement.

Fig. 5(a) is the original image that is relatively blurry and dark. Fig. 5(b) is the result enhanced by both the histogram enhancement and texture enhancement with *P*=1.3. Image 5(b) is more vivid than image 5(a), and even holes that are hard to recognize in image (a) are easy to be seen in image (b). From the two enhanced results, it can conclude that there is no under-enhancement or over-enhancement.

5. Conclusions

Fuzzy logic is a very powerful tool to analyze the information in an uncertain system. In this paper, we propose a piecewise fuzzy concept and use it to do the contrast enhancement of color images. A global method, the histogram enhancement, and a local method, the texture enhancement, are proposed. The two methods are combined to do the enhancement in the experiments. Because we employ both the global and local information, the experimental results show that the proposed algorithm is very effective and efficient in contrast enhancement of color images.

6. References

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