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An Improved Image Enhancement Algorithm Based on Fuzzy Set

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Abstract

According to the shortcomings of the traditional fuzzy enhancement algorithms, several improvements are proposed. In the improved algorithm, the membership functions and fuzzy enhancement operator are made up of piecewise continuous functions, and the image is divided into two regions by OTSU method, one is high grey region, the other is low grey region, pixels in the high grey region are enhanced, and pixels in the low grey region are reduced. Simulation results show that this algorithm has good ability to enhance blur and little edges, and it is an effective and efficient way to increase image's contrast.

Index Terms—*fuzzy set, image enhancement, membership function, piecewise continous functions*

Introduction

In image processing, such problems as the inexactness and uncertainty which are also called fuzziness often appear, therefore, many scholars had tried to apply fuzzy set theory for image processing and recognition. Pal and King brought out a fuzzy algorithm for image enhancement first, and good results are gotten when this algorithm is applied to pattern recognition and medical image processing[1]. But this algorithm also has such shortcomings as improper enhancement, long time cost, etc. For overcoming these shortcomings, some improved algorithms are presented and good effects are gotten[2-5]. Therefore, the image enhancement technology based on fuzzy set is worthy of attention, better results are often gotten than using traditional ways when it is applied for image processing.

In this paper, a new member function and fuzzy enhancement operator are proposed, and simulation results show that this algorithm will bring better effect.

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Procedure of pal fuzzy enhancement

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A. Image Fuzzy Feature Plane

According to the concepts of fuzzy set, an M×N two dimensional image whose maximal grey level is L can be looked as fuzzy pixels sets, which are expressed as:

$$X = \begin{bmatrix} \frac{p_{11}}{X_{11}} & \frac{p_{12}}{X_{12}} & \cdots & \frac{p_{1N}}{X_{1N}} \\ \frac{p_{21}}{X_{21}} & \frac{p_{22}}{X_{22}} & \cdots & \frac{p_{2N}}{X_{2N}} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{p_{M1}}{X_{M1}} & \frac{p_{M2}}{X_{M2}} & \cdots & \frac{p_{MN}}{X_{MN}} \end{bmatrix} \quad (1)$$

or $X = \bigcup_{i=1}^{M}\bigcup_{j=1}^{N} \frac{p_{ij}}{X_{ij}}$, i=1,2,……,M; j = 1,2,……,N;

In the above equation, X_{ij} is the value of pixel (i, j), p_{ij} is the pixel (i, j) membership grade, $p_{ij} \in [0,1]$, all p_{ij} consist the image fuzzy feature plane, p_{ij} can be calculated by fuzzy membership function, various effects can be gotten with various membership functions. The membership function defined by Pal is as follows:

$$p_{ij} = F(X_{ij}) = [1 + (\frac{(L-1) - X_{ij}}{F_d})]^{-F_e} \quad (2)$$

In the above equation, F_d is called reciprocal fuzzy factor, F_e is called exponent fuzzy factor, and F_e is often made equal to 2. When $p_{ij} = p_c = F(X_C) = 0.5$, X_C is called pivotal point, pivotal point can be acquired self-adaptively by OTSU method [6] F_d can be calculated through X_C and F_e. Fig.1 shows the curve of Pal membership function, it can be seen that the degree of membership gotten by this membership function belongs to (0,1] space interval, that is to say, the minimal value of p_{ij} is greater than zero.

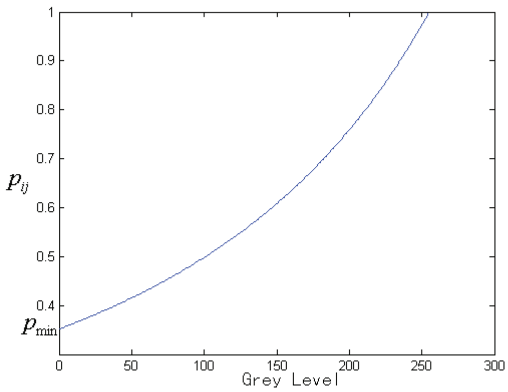


Fig.1 Pal membership function curve

B. Transformation of Fuzzy Membership Grade

Nonlinear transformation of fuzzy membership grade p_{ij} is carried out to increase image's contrast. The nonlinear transform function defined by Pal is as follows.

$$p_{ij}^{'} = I_r(p_{ij}) = I_1(I_{r-1}(p_{ij})) \quad r = 1,2,3,4,... \tag{3}$$

And,

$$I_1(p_{ij}) = \begin{cases} 2p_{ij}^2 ....0 \le p_{ij} \le 0.5 \\ 1-2(1-p_{ij})^2 ...0.5 < p_{ij} \le 1 \end{cases} \tag{4}$$

A new fuzzy feature plane will come into being after (3) is used, when the cycle count r approach infinity, a two-value image will be produced, therefore, the fuzzy enhancement turns into segmentation in fact. Generally, an image can be enhanced obviously after (3) is applied finite times. In the Pal fuzzy enhancement algorithm, the threshold p_c at pivotal point is selected as 0.5, which may not be scientific to some images, and this is an important reason why Pal algorithm sometime can't bring good results.

C. Inverse Transformation of Fuzzy Membership Grade

After nonlinear transforming of fuzzy membership grade, $p_{ij}^{'}$ is gotten, and then the enhanced image can be acquired by inverse transformation of $p_{ij}^{'}$, the inverse equation is as follows.

$$X_{ij}^{'} = F^{-1}(p_{ij}^{'}) = L - 1 + F_d[1 - (p_{ij}^{'})^{-\frac{1}{F_e}}] \tag{5}$$

After transforming by using (4), such conditions that some fuzzy membership grades $p_{ij}^{'}$ are less than $p_{\min}$ in Fig.1 will happen, therefore, the $X_{ij}^{'}$ gotten will be less than zero. Obviously, the image grey level can not be negative; therefore, pixels' grey values which are less than zero are set to zero in Pal algorithm. But, it can cause another question that some low grey information is lost and the effect of fuzzy enhancement can be affected seriously.

Iii. New fuzzy enhancement algorithm

For avoiding the shortcomings of Pal algorithm, the membership function is reconstructed first. Because the Pal algorithm has relations with pivotal point, and the pivotal point has relation with threshold p_c which is set to 0.5 improperly. Therefore, the new membership function should eliminate the influence of threshold p_c, it is as follows.

$$p_{ij} = F(X_{ij}) = \begin{cases} s_1 tg^2\left(\frac{\pi X_{ij}}{4(L-1)}\right) .... \quad 0 \le X_{ij} \le X_T \\ 1 - s_2\left(1 - tg\frac{\pi X_{ij}}{4(L-1)}\right)^2 .... \quad X_T < X_{ij} \le L-1 \end{cases} \tag{6}$$

In order to make above equations continuous, the following conditions must be met.

$$s_1 = \frac{X_T}{(L-1)tg^2(\frac{\pi X_T}{4(L-1)})}$$

$$s_2 = \frac{L-1-X_T}{(L-1)(1-tg\frac{\pi X_T}{4(L-1)})^2}$$

In (6), X_T is the pivotal point gotten by using OTSU method, therefore, the image can be divided into two regions which are low grey region and high grey region. The main idea of fuzzy enhancement is to carry out weakening operation in low grey region so that the pixels' grey levels in it will become lower, and to carry out strengthening operation in high grey region so that the pixels' grey levels will become higher. Fig.2 shows the curves of (6) with various X_T, the following features can be seen.

Firstly, the grey levels are map to interval [0, 1], and when the grey level is equal to X_T, the corresponding p_{ij} is equal to $\frac{X_T}{L-1}$. Secondly, the whole function is continuous, which is helpful for preventing the membership grade from changing abruptly to form false edges or make the image enhanced excessively. Finally, as tangent function is used as membership function, in the interval [0 , X_T], the less the grey level X_{ij} is, the more the membership grade p_{ij} is reduced, and p_{ij} is less than $\frac{X_{ij}}{L-1}$; while in the interval (X_T ,L-1), p_{ij} is bigger than $\frac{X_{ij}}{L-1}$, it is in favour of weakening the pixels in low grey region and increasing the pixels in high grey region.

Additionally, if X_T is equal to 0 or L-1, the image to be processed must be a two-value image, it is not necessary to process it.

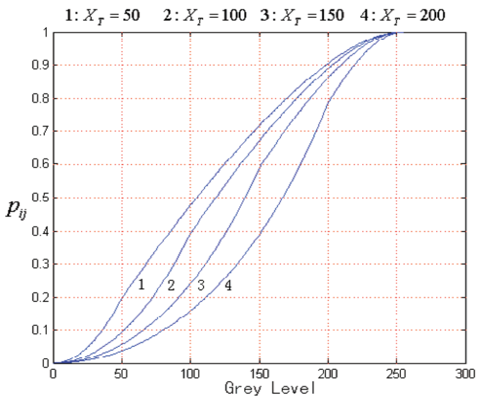


Fig.2 Curves of membership function

Then, reconstruct the fuzzy enhancement operator in (4), suppose p_T is the membership grade corresponding to the pivotal point X_T, (4) can be modified as follows.

$$p'_{ij} = \begin{cases} k_1 p_{ij}^2 \dots\dots\dots\dots\dots\dots & 0 \le p_{ij} \le p_T \\ 1 - k_2(1-p_{ij})^2 \dots & p_T < p_{ij} \le 1 \end{cases} \tag{7}$$

In order to make above equations continuous,

$$k_1 = \frac{1}{p_T} \qquad k_2 = \frac{1}{1-p_T}$$

Fig.3 shows the curves of (7) with various p_T. Obviously, this operator decreases the p_{ij} which is less than p_T, and enlarges the p_{ij} which is bigger than p_T. Furthermore, the whole function transit smoothly at the pivotal point, which is beneficial to strengthen the edges without excessive enhancement.

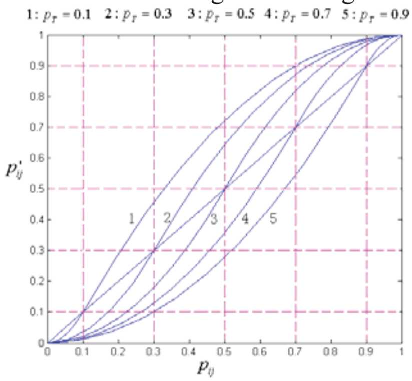


Fig.3 Fuzzy enhancement operator curves with various p_T

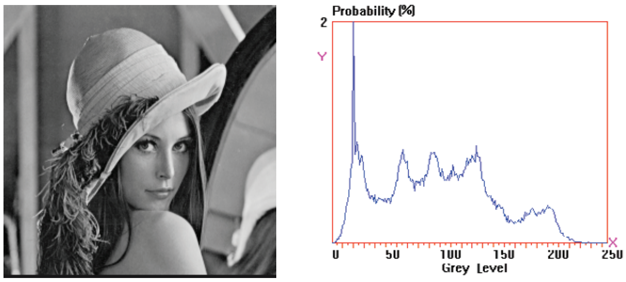
The enhanced image can be gotten by inverse transformation; the inverse equation is as follow.

$$X'_{ij} = F^{-1}(p'_{ij})$$
$$= \begin{cases} \dfrac{4(L-1)}{\pi} arctg(\sqrt{\dfrac{p'_{ij}}{s_1}}) & 0 \le p'_{ij} \le p_T \\ \dfrac{4(L-1)}{\pi} arctg(1-\sqrt{\dfrac{1-p'_{ij}}{s_2}}) & p_T < p'_{ij} \le 1 \end{cases} \tag{8}$$

From above equations, it can be seen that $p'_{ij} \in [0,1]$ and $X'_{ij} \in [0,255]$. Therefore, the new algorithm will not bring out hard cutting phenomenon, and the low grey level information will not be lost.

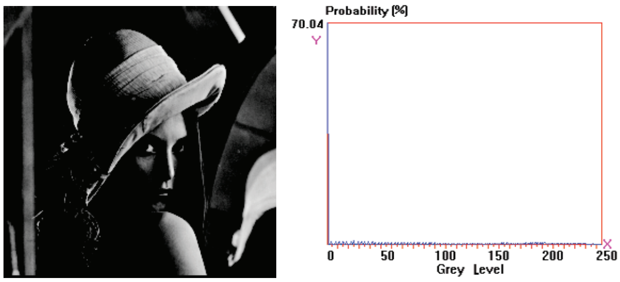
Simulation results and analysis

Simulation with Lena image is carried out by using the improved fuzzy enhancement algorithm in this paper and Pal algorithm(r is enhancement times). The whole algorithm is programmed with VC++6.0.



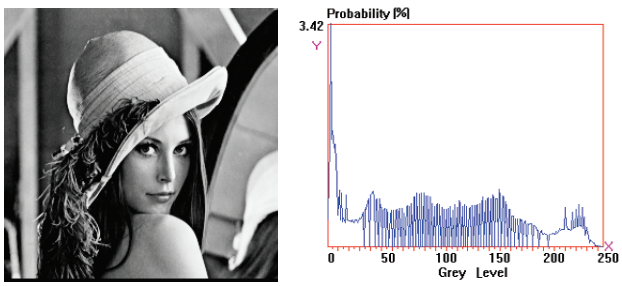
(a) Original image of Lena (b) Histogram

Fig.4 Original image of Lena and its histogram



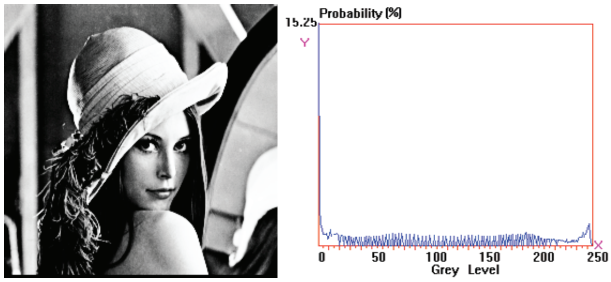
(a) Image after enhancing (b) Histogram

Fig.5 Image enhanced by using Pal algorithm (r=2) and its histogram



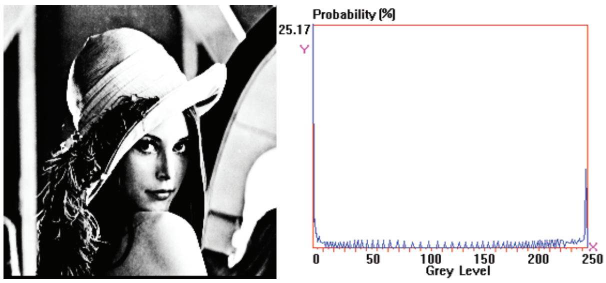
(a) Image after enhancing (b) Histogram

Fig.6 Image enhanced by using improved algorithm (r=1) and its histogram



(a) Image after enhancing (b) Histogram

Fig.7 Image enhanced by using improved algorithm (r=2) and its histogram



(a) Image after enhancing (b) Histogram

Fig.8 Image enhanced by using improved algorithm (r=3) and its histogram

From Fig.4, it can be seen that the contrast of original image is not high. Fig.5 shows the image enhanced by using Pal algorithm two times and its histogram, it can be seen that the enhanced image almost become a binary image, but much low grey information is lost. Fig.6, Fig.7 and Fig.8 are images by using the improved algorithm brought out in this paper one, two and three times respectively. Obviously, better results can be gotten and the image's contrast can be increase much by using the improved algorithm than using Pal algorithm; when r=1, the enhancement is not enough to make the image edges distinct; when r=2, the image edges is very clear; when r=3, the image edges vanish a little; additionally, when r enlarges gradually, the image becomes binary image step by step. Therefore, when the improved fuzzy algorithm is applied for image enhancement, r=2 or r=3 is suitable, which is helpful for increasing image processing efficiency.

Conlusion

A new continuous membership function and fuzzy enhancement operator are proposed in this paper for solving the shortcomings of traditional fuzzy algorithm. When using this algorithm for image enhancement, the image contrast will be increased obviously, the image edge will be kept well, and good results will be gotten with only 2~3 times enhancement. Therefore, this algorithm is an effective way for image enhancement.

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