Fuzzy Image Enhancement Method based on a New Intensifier Operator

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***Abstract*—In recent years, fuzzy image enhancement methods have been widely applied in image enhancement, which generally consists of three steps: fuzzification, modify membership(using intensifier (INT) operator), and defuzzification. This paper proposed a new INT operator used in fuzzy image enhancement. The INT operator is adjustable for different test images. The image enhancement method is as follows, firstly, calculate the image threshold (T) using the OTSU method. Secondly, calculate pivotal point p corresponding to T, and find the corresponding INT operator function. Finally, use the INT operator in fuzzy Image Enhancement. The INT operator is used multiple times in the image processing process to obtain multiple result images. Comparative experiments show that the proposed new INT operator has better image enhancement effect when INT operator is applied at the same number of times. On the other hand, more intermediate process result images can also be obtained through the proposed new INT operator. More result images can provide material resources for the subsequent image processing.**

***Keywords*—Image enhancement; intensifier operator; threshold; pivotal point**

I. Introduction

Image enhancement's aim is to highlight useful information and remove useless information. The widely used image enhancement algorithms include gray transformation method [1]–[5], histogram equalization (HE) method [6]–[8], wavelet transform method [9]–[11] and basis algorithm Retinex method [12], [13] in color constancy theory. Gray transformation method is to directly apply the transformation function on the gray level to produce a new gray level. This method is relatively simple and easy to be implemented. HE method can increase image dynamic range and improve image contrast by making the probability density function of image gray level meet the form of approximately uniform distribution. The wavelet transform method divides the image into low frequency image and high frequency image, and enhances the different frequencies image to highlight the details of the image. Retinex method removes the influence of the illuminance component in the original image, and obtains the result image.

Image enhancement is widely used in many fields and many different types of images, such as infrared images, remote sensing images, underwater images, medical images and so on [14]–[17]. In recent years, fuzzy enhancement methods have been developed rapidly. Pal-King method [18] is the first proposed fuzzy image enhancement method, and has been applied in many fields until now. Generally, the fuzzy enhancement method consists of three steps: calculate the image pixels' membership by fuzzification, adjust the membership using intensifier (INT) operator, and output new pixels' gray level by defuzzification. In the development of fuzzy image enhacement method, many functions of fuzzification, INT operator and defuzzification have been proposed. We introduce some common fuzzy enhancement methods. Li et al. [19] proposed a fast and reliable image enhancement technique based upon the fuzzy relaxation algorithm. Different orders of fuzzy membership functions and different rank statistics are attempted to improve the enhancement speed and quality, respectively. Hanmandlu et al. [20] used a Gaussian membership function to fuzzify the image information in spatial domain, and introduced a global INT operator which contains three parameters. Aiming at the membership cannot fill the interval $[0, 1]$ and the pivotal point p of INT operator in Pal-King method is always the same ($p \equiv 0.5$), Liu [21] proposed a fuzzification function based on tangent function and an INT operator with an adjustable parameter. Mahashwari et al. [22] proposed a defuzzification function. Hasikin et al. [23] proposed a new fuzzy intensity method to distinguish between the dark and bright regions. This method is computed by considering the average intensity and deviation of the intensity distribution of the image. The input image is enhanced using a power-law transformation. Singh et al. [24] proposed a new INT operator and a defuzzification method. Dawayet et al. [25] proposed a fuzzification and a defuzzification method. Yang et al. [26] proposed an INT operator based on cycloid arc length function. Fuzzy C-means clustering is also a good method for image enhancement [27]–[29]. More and more researchers are studying the fuzzy image enhancement method. The fuzzy image enhancement method has more and more unique advantages in the image enhancement field.

In existing methods, almost all fuzzification functions, INT operator functions and defuzzification functions are either piecewise functions or have a pivotal point p that cannot be adjusted ($p \equiv 0.5$). In the realization of the algorithm (such as Matlab), the piecewise function needs to add the judgment statement in the coding, and use the judgment statement repeatedly in the calculation. This result will cause the computation time to increase. In view of pivotal point $p \equiv 0.5$ and the possible shortcomings of piecewise function, this paper proposed an INT operator that is used in fuzzy image enhancement method. The INT operator function is made up by power function and has a variable parameter λ. For different test images, the parameter λ is determined prior to image enhancement. In Section 3, compare the image enhancement of the INT operator in [21] and the proposed INT operator using the same fuzzification function, and defuzzification function. The experimental results show that when INT operator process

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the same times, the proposed INT operator can achieve a better image enhancement, and even if the proposed INT operator is used many times, it still has a good enhancement effect.

II. Methodology

Fuzzy image enhancement includes some steps: (1) using fuzzification to trasform the image pixels' gray level to its membership, (2) modifying membership using intensifier (INT) operator, and (3) calculating pixels' new gray level by defuzzification. In this section, first, we introduce the common INT operators, and then propose a new INT operator.

A. INT Operators

Although researchers have proposed many INT operators, there are two INT operators that appear most frequently in papers because they are simple to calculate and easy to manipulate. The first INT operator is a function made up of quadratic functions [18],

$$y = f(x) = \begin{cases} 2x^2, & 0 \le x \le 0.5, \\ 1 - 2(1-x)^2, & 0.5 < x \le 1. \end{cases} \tag{1}$$

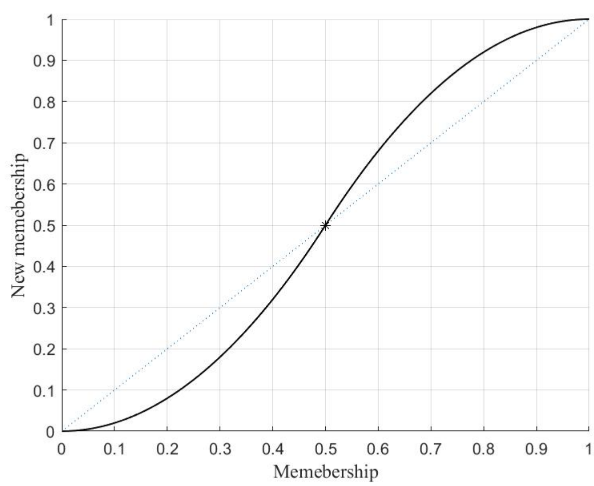

Fig. 1. The INT Operator $y = f(x)$.

Fig. 1 shows that the graph of INT operator $y = f(x)$. For all test images, the INT operator $y = f(x)$'s pivotal point (function piecewise point or inflection point) p is identically 0.5. This obviously has some limitations. In avoiding the shortcomings of INT operator $y = f(x)$, the improved INT operator is presented as follows [21]:

$$y = g(x) = \begin{cases} \frac{x^2}{p}, & 0 \le x \le p, \\ 1 - \frac{(1-x)^2}{1-p}, & p < x \le 1. \end{cases} \tag{2}$$

The INT operator $y = g(x)$ can adjust the point p according to the characteristics of the test image. Fig. 2 shows that the INT operator $y = g(x)$ can reduce the points which less than p, and enlarge the points which more than p. Both INT operator $y = f(x)$ and INT operator $y = g(x)$ are piecewise functions. The piecewise functions have some disadvantages in calculation, especially in the programming implementation (such as Matlab), judgment statements will be used many times in the program, which increases the amount of calculation. Now, we propose a new INT operator,

$$y = \varphi(x) = \frac{2x^\lambda}{1 + x^\lambda}, \quad 0 \le x \le 1. \tag{3}$$

Where $\lambda = 1 - \log_p(2-p)$. The INT operator $y = \varphi(x)$ is also can adjust the point p and its implementation procedure is more simplified. It does not need to use a judgment statement in the program. Fig. 2 shows that the graph of INT operator $y = g(x)$ and INT operator $y = \varphi(x)$.

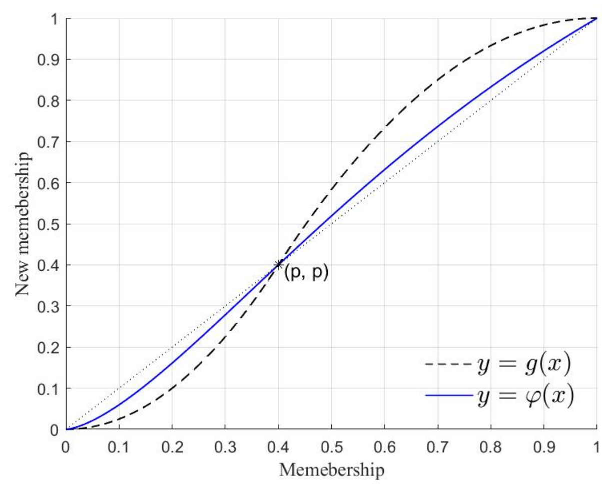

Fig. 2. An Example for of the INT Operators $y = g(x)$ and $y = \varphi(x)$ when $p = 0.4$.

B. Fuzzy Contrast Enhancement

Image $I = \{x_{ij} | i = 1, 2, 3, \cdots, m, j = 1, 2, 3, \cdots, n\}$, where x_{ij} is gray level of the pixel in row i and column j of the image. To compare the effect of INT operators $y = g(x)$ and $y = \varphi(x)$, we use the same fuzzification and defuzzification. Fuzzy contrast enhancement includes three steps as follow:

(1)Gray level fuzzification (Counting pixels' membership)

$$\mu_{ij} = \mu(x_{ij}) = \frac{x_{ij} - x_{min}}{x_{max} - x_{min}} \tag{4}$$

where, $x_{max}(x_{min})$ is the maximum(minimum) pixel's gray level of the test image.

(2)Membership modification using INT operator:

$$\hat{y}_{ij} = I_t(u_{ij}) = I_1(I_{t-1}(u_{ij})) \quad t = 1, 2, 3, \cdots$$

INT operator: $I_1(u_{ij}) = g(u_{ij})$, or INT operator: $I_1(u_{ij}) = \varphi(x_{ij})$.

In the Eq.(2) and Eq.(3), $p = \mu(T)$, T is the test image threshold by the OTSU method.
(3)Pixels' new gray level by defuzzification

$$y_{ij} = (x_{max} - x_{min})\hat{y}_{ij} + x_{min}. \tag{5}$$

$I_{enh} = \{y_{ij} | i = 1, 2, 3, \cdots, m, j = 1, 2, 3, \cdots, n\}$ is the result image.

III. Experimental Results and Analysis

Structural similarity(SSIM) is commonly used to evaluate the image enhancement effect. This section also use the SSIM value as an objective evaluation criterion for image enhancement.

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}. \tag{6}$$

In equation (6), μ_x is the mean of x, μ_y is the mean of y, σ_x^2 is the variance of x, σ_y^2 is the variance of y, σ_{xy} is the covariance of x and y. c_1 and c_2 are constants [30].

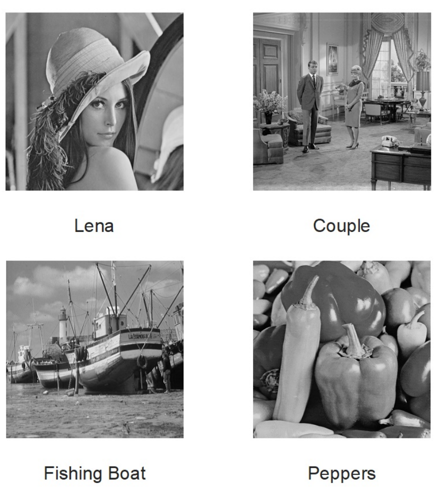

Fig. 3. Test Images.

Fig. 3 shows the test images. INT operator $y = g(x)$ and INT operator $y = \varphi(x)$ processed test images for 2 and 8 times, respectively.

Fig. 4 shows that at the same number of processing times, the image processed by INT operator $y = \varphi(x)$ is closer to the original image, and more intermediate process images can be obtained. When the INT operators are used the same number of times, the INT operator $y = \varphi(x)$ has a higher SSIM value. It achieves a better image enhancement effect.

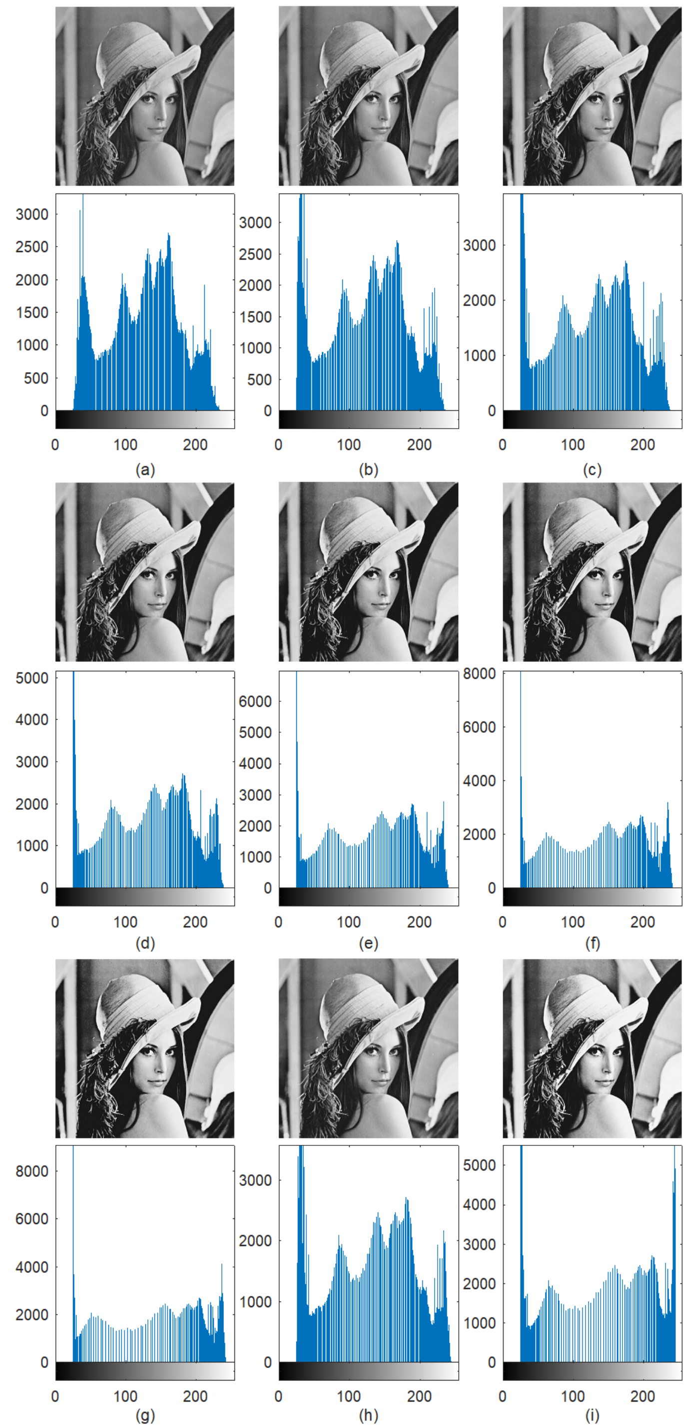

Fig. 4. Enhancement Results of the Lena and its Histogram. (a)-(g). Processed by Proposed INT Operator $y = \varphi(x)$ Times:1-7; (h)-(i). Processed by Method with INT Operator $y = g(x)$ Times:1-2.

TABLE I. STRUCTURAL SIMILARITY (SSIM) TEST RESULTS

Method \ Test images		Lena	Couple	Fishing Boat	Peppers
processed by INT operator $y = g(x)$	t = 1	0.9341	0.9000	0.9016	0.8871
	t = 2	0.7963	0.7125	0.7462	0.6793
processed by proposed INT operator $y = \varphi(x)$	t = 1	0.9916	0.9882	0.9863	0.9781
	t = 2	0.9681	0.9538	0.9485	0.9244
	t = 3	0.9325	0.9044	0.8987	0.8615
	t = 4	0.8911	0.8477	0.8514	0.7968
	t = 5	0.8485	0.7924	0.8117	0.7330
	t = 6	0.8090	0.7422	0.7785	0.6720
	t = 7	0.7725	**0.6990**	0.7503	0.6181
	t = 8	0.7398	0.6615	0.7238	0.5736

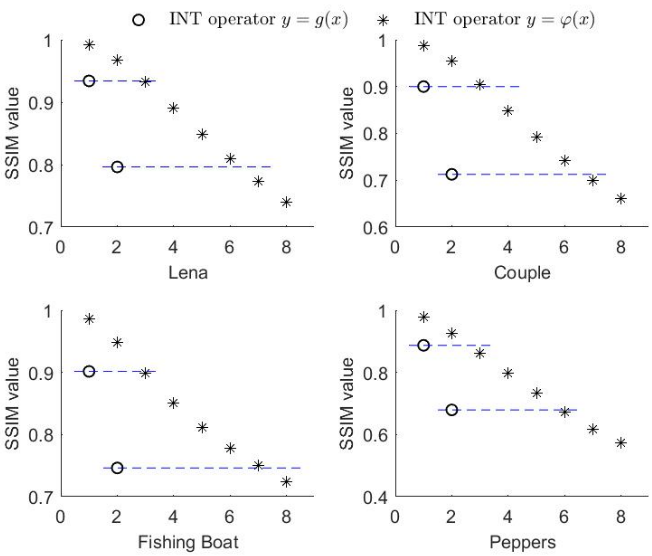

Fig. 5. The SSIM Values when the Test Images are Processed by Fuzzy Image Enhancement Method using INT Operators t Times.

In Table I, for the convenience of expression, denoted S(image, INT operator, t) means that the SSIM value of image and the image which is processed t times by INT operator. For example, S(Couple, $y = \varphi(x)$, 7) = 0.6990. Table I shows S(Couple, $y = \varphi(x)$, 1) $>$ S(Couple, $y = \varphi(x)$, 2) $>$ S(Couple, $y = \varphi(x)$, 3) $>$ S(Couple, $y = g(x)$, 1). This means that when INT operator $y = g(x)$ processed 1 time, the INT operator $y = \varphi(x)$ can processed 3 times. All of the 3 result images' SSIM values are higher than the result image processed by the INT operator $y = g(x)$ 1 time. For other test images, a similar phenomenon exists. Fig. 5 shows this more clearly. For example, Fig. 5 (Peppers) shows that S(Peppers, $y = \varphi(x)$, 1) $>$ S(Peppers, $y = \varphi(x)$, 2) $>$ S(Peppers, $y = g(x)$, 1) $>$ S(Peppers, $y = \varphi(x)$, 3) $>$ S(Peppers, $y = \varphi(x)$, 4) $>$ S(Peppers, $y = \varphi(x)$, 5) $>$ S(Peppers, $y = g(x)$, 2) $>$ S(Peppers, $y = \varphi(x)$, 6) $>$ S(Peppers, $y = \varphi(x)$, 7) $>$ S(Peppers, $y = \varphi(x)$, 8). Fig. 5 is a visual representation of Table I.

IV. CONCLUSION

This paper proposed a new intensifier(INT) operator used in fuzzy image enhancement. It has the following advantages. First, compared to the INT operator which is made up by a piecewise function, the proposed INT operator has an advantage in program implementation that it does not require writing judgment statements. Second, due to the range of change of the proposed INT operator is small (see Fig. 2), the result image with higher SSIM value can be obtained after the INT operator is multiple applied. This means that it achieves a better image enhancement effect. It can produce more process images. More images of the process can provide material resources for the subsequent image processing, and could help in other areas of research. In future work, we will investigate whether it can be used in other fields.

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