Image Enhancement Using Fuzzy Logic Techniques

Preeti Mittal, R. K. Saini and Neeraj Kumar Jain

Abstract Image enhancement is the preprocessing task in digital image processing. It helps to improve the appearance or perception of the image so that the image can be used for analytics and human visual system. Image enhancement techniques lie in three broad categories—spatial domain, frequency domain, and fuzzy domain-based enhancement. A lot of work has been done on image enhancement. Most of the work has been done/performed on grayscale image. This paper concentrates on image enhancement using fuzzy logic approach and gives an insight into previous research work and future perspectives.

Keywords Image enhancement · Fuzzy logic techniques · Review · Future perspective · Performance measures

1 Introduction

Image enhancement is the preprocessing task of digital image processing. It is used to improve the appearance or perception of image so that enhanced image can be used for human visual system or analytics. It is required due to limiting capabilities of the hardware used for capturing the images, inadequate lighting conditions, and environmental conditions such as fog, sunlight, cloud cover, etc.

During image acquisition/digitization, images may contain vagueness or uncertainty in the form of imprecise boundaries and the intensities of colors. The quality of an image is measured objectively using mathematical functions and subjectively.

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Subjective measures are based on human perception of image and human perception is fuzzy in nature because an image is considered as good differently by different people. These lead the application of fuzzy logic in image processing because fuzzy logic deals with vagueness and uncertainty.

Image enhancement techniques are categorized into three categories—spatial domain-based enhancement, frequency domain-based enhancement, and fuzzy domain-based enhancement. In spatial domain-based enhancement, the algorithm works directly on the pixel intensity of the image. In frequency domain-based approach, the image is transformed into frequency domain such as DCT, DWT, or Fourier transformation. In fuzzy domain-based enhancement, the image is transformed into fuzzy property plane using some membership function such as Gaussian, triangular, or any other functions.

Various spatial domain enhancement techniques such as histogram equalization, histogram specification, iterative histogram modification, adaptive neighborhood equalization exist in literature. Most of the histogram enhancement techniques suffer from washed out effect and can amplify the existing noise [18]. Frequency domain techniques are good but computing a two-dimensional transform for an image (large array of intensities) is a very time-consuming task so they are not good for real-time applications [12].

The rest of the paper is organized as follows: Sect. 2 gives information about fuzzy set theory. Section 3 defines the fuzzy image. Section 4 presents the overview on architecture of fuzzy image processing. Section 5 describes performance evaluation measures used in fuzzy image processing. Section 6 discusses the previous work in detail. Future directions and conclusion are given in Sects. 7 and 8, respectively.

2 Fuzzy Set Theory

Lotfi A. Zadeh, a professor of computer science at the University of California, Berkeley, introduced the concept of fuzzy logic in 1965. Fuzzy set [34] is used as a problem-solving tool between the precision of classical mathematics and the inherent imprecision of the real world and for the problems which are having variables vague in nature. Fuzzy set is applied when the pattern indeterminacy exists because of inherent variability or vagueness rather than randomness [22].

3 Fuzzy Image Definition

An image I with the intensity level in the range $[0, L - 1]$ can be considered as an array of fuzzy singletons and represented in fuzzy notation as

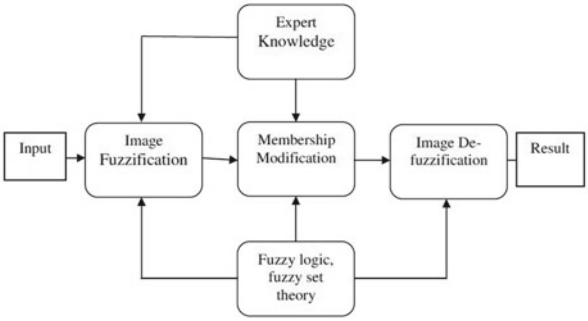

Fig. 1 Fuzzy image processing

$$I = \bigcup_{m=1}^{M} \bigcup_{n=1}^{N} \frac{\mu_{mn}}{i_{mn}} = \{\mu_{mn}/i_{mn}\} \tag{1}$$

where m = 1, 2, 3, . . ., M and n = 1, 2, 3, . . ., N.

4 Fuzzy Image Enhancement

Fuzzy image enhancement technique takes an image as input and provides an output image which is of better quality than input image. Fuzzy image processing is usually divided into three stages: image fuzzification, modification of membership values, and image defuzzification as shown in Fig. 1. Fuzzification and defuzzification have to be performed due to the absence of hardware. The power of the fuzzy image enhancement system lies in second step as the image contrast is improved by changing the membership values using transformation function.

Image fuzzification is very first task. Image is converted into fuzzy property plane using some membership function such as Gaussian, triangular, or some other functions. The image is converted from fuzzy property plane into spatial domain using inverse function of the function used for fuzzification.

5 Performance Evaluation Measures

The quality of image can be measured objectively using mathematical functions or subjectively. There are many mathematical functions or measures such as mean square error, index of fuzziness, entropy, peak signal-to-noise ratio, contrast improvement index to evaluate the quality of enhanced image.

5.1 Mean Square Error (MSE)

Mean square error (MSE) is calculated between original/acquired image and enhanced image as

$$MSE = \frac{1}{M \cdot N} \sum_{i=1}^{M} \sum_{j=1}^{N} (OI(i, j) - EI(i, j))^2 \tag{2}$$

Lower the value of MSE, lower the error, and the enhanced image is closer to the original image.

5.2 Peak Signal-to-Noise Ratio (PSNR)

PSNR is used as a quality measurement between original image and enhanced image and calculated as

$$PSNR = 10 \log_{10} \frac{L_{MAX}^2}{MSE} \tag{3}$$

L_{MAX} is the maximum intensity value (i.e., 255), and MSE is mean square error between original and enhanced image. The higher value of PSNR indicates the better quality of enhanced image.

5.3 Linear Index of Fuzziness

Linear index of fuzziness (IOF) provides the information about the fuzziness or vagueness or uncertainty present in the image by measuring the distance between fuzzy property plane and its nearest ordinary plane. Amount of fuzziness is 0, if all membership grades are 0 or 1. IOF reaches its maximum if all membership grades are equal to 0.5. An enhanced image is considered better if there is lower amount of fuzziness presented in enhanced image than original image.

$$LI = \gamma (I) = \frac{2}{M \cdot N} \sum_{i=1}^{M} \sum_{j=1}^{N} min(\mu_{ij}, 1 - \mu_{ij}) \tag{4}$$

5.4 Fuzzy Entropy

Entropy is the statistical measure of uncertainty present in the image to characterize the texture of input image and is defined in [4] as

$$E(X) = \frac{1}{M \cdot N} \sum_{i=1}^{M} \sum_{j=1}^{N} S_n\left(\mu_X\left(x_{ij}\right)\right) \tag{5}$$

where $S_n(\cdot)$ is a Shannon function.

$$S_n\left(\mu_X\left(x_{ij}\right)\right) = -\mu_X\left(x_{ij}\right)\log_2 \mu_X\left(x_{ij}\right) - \left(1 - \mu_X\left(x_{ij}\right)\right)\log_2\left(1 - \mu_X\left(x_{ij}\right)\right) \tag{6}$$

where i = 1, 2, 3, . . ., M and j = 1, 2, 3, . . ., N.

5.5 Contrast Improvement Index

The contrast improvement index (CII) is a ratio of average values of local contrasts in original image and enhanced image [24]. Local contrast with 3 × 3 window is measured as $\frac{max - min}{max + min}$

$$CII = \frac{C_{Enhanced}}{C_{Original}} \tag{7}$$

6 Related Work

In the past few years, various researchers proposed algorithms in the field of fuzzy image enhancement. Pal et al. are said to be pioneer to use fuzzy set theory in the field of image enhancement. In 1980, Pal et al. transformed the image from spatial domain to fuzzy property domain before processing. In fuzzy property plane, an image is considered as an array of fuzzy singletons, each with a membership value denoting the degree of having some brightness level. The membership function was modified using fuzzy contrast intensification operator (INT) to enhance the contrast [22]. This concept was also applied for gray image enhancement with smoothing operation in [21]. The limitation of this INT operator is that it needs to be applied successively to the image to attain the desired enhancement.

Techniques based on modification of image histogram are the most popular among researchers due to the simplicity of image histogram. Tizhoosh and Fochem (1995) introduced a new technique based on fuzzy histogram hyperbolization (FHH). In this, a very simple function was used to fuzzify the image and FHH to change the membership values and gray levels [28]. Sheet et al. (2010) [27] and Raju and Nair (2014) [24] proposed fuzzy-based histogram equalization technique to enhance the low contrast images for better results.

The other approaches for image enhancement are by using fuzzy logic IF-THEN-ELSE rules [6, 25] and fuzzy relations [1]. Russo and Ramposi (1995) proposed an approach using fuzzy rules to sharpen details of the image and used local luminance difference as variable [25]. Choi and Krishnapuram (1995) introduced a fuzzy rule-based system to remove impulsive noise, to smooth impulsive noise, and to enhance edges [6].

In some cases, the global fuzzy image enhancement techniques fail to achieve satisfactory results. To solve this problem, Tizhoosh et al. (1997) introduced a locally adaptive version of [22, 28]. To find the minimum and maximum gray levels for the calculation of membership function, they found the minimum and maximum of subimages (30×30 windows) and interpolated these values to obtain corresponding values for each pixel [29].

To improve the limitation of INT operator, Hanmandlu et al. (1997) proposed an approach in which a new contrast intensification operator (NINT) was used for the enhancement of gray images and Gaussian type membership function with a new fuzzifier (fh) was used to model intensities into fuzzy domain. NINT does not change uniformly. It is almost linear at middle and changes marginally at extremes. Fuzzifier was obtained by maximizing the fuzzy contrast [16].

Tizhoosh et al. (1998) introduced a new algorithm for contrast enhancement of grayscale images using Sugeno's involutive fuzzy complements, called λ-complements at the place of Zadeh's complement of fuzzy sets. Membership values were modified using optimal value of λ which was optimized by maximizing index of fuzziness [30].

Cheng and Xu (2000) [4] proposed adaptive fuzzy contrast enhancement method with adaptive power variation. The image was fuzzified using S-function. The parameters a, c were measured based on the peaks in the histogram and parameter b was optimized based on the principle of maximum entropy. The global and local information about contrast were used to enhance the contrast. This method requires a lot of calculation for contrast enhancement. So to speed up the calculation, the original image was divided into subimages and the said process was applied on the subimages to get the enhanced sample mapping and the contrast of any pixel was calculated by interpolating the surrounding mapping. This technique can prevent over-enhancement. [5] used this method for mammogram contrast enhancement.

Hanmandlu et al. (2003) extended their previous work and applied NINT operator on color images by converting RGB images into HSV color model before fuzzification [15]. NINT was having a parameter t for the enhancement of color images. This parameter was calculated globally by minimizing the fuzzy entropy of the image information. These algorithms enhance the contrast of image globally/locally without considering the exposure of an image. Exposure indicates the amount of intensity exposition and characterizes the image as underexposed or overexposed image. Hanmandlu and Jha (2006) introduced a global contrast intensification operator (GINT) with three parameters: the intensification parameter (t), the fuzzifier (fh), and the crossover point (μ(c)), for enhancement of underexposed color images. The parameters were calculated globally by minimizing the fuzzy entropy of the image information with respect to the fuzzy contrast-based quality factor Qf and entropy-based quality factor Qe and the corresponding visual factors [14]. Using this method, a good improvement was seen in underexposed images.

This work was extended by Hanmandlu et al. (2009) and the image was divided into underexposed and overexposed regions based on exposure value. The parameters were calculated by minimizing the objective functions using bacterial foraging technique [17]. Hanmandlu et al. (2013) introduced a new objective measure, contrast information factor, which was optimized using particle swarm optimization to get the values of parameters for GINT for the enhancement of color images [12]. Cai and Qian (2009) proposed a technique for night color image enhancement. They enhanced the dark regions and restrained the glaring regions [2]. Verma et al. (2012) used artificial ant colony system and visual factor as objective function to optimize the parameters used for fuzzification and membership value modification [32].

Hasikin and Isa (2012) proposed a technique for enhancement of grayscale nonuniform illumination images and used flexible S-shaped function to fuzzify the intensity of image pixels and membership function was modified using power-law transformation for overexposed regions and saturation operator for underexposed regions to enhance the image. The parameters used in S-shaped functions were specified using maximized value of fuzzy entropy and index of fuzziness [18]. A. H. Mohamad (2016) introduced a new contrast intensification operator using logarithmic function with three parameters at the place of INT operator of [22] and Gaussian function to model the intensities in fuzzy property plane from spatial domain [20]. Puniani and Arora (2016) performed the fuzzy image enhancement technique for color images on L*a*b color space followed by smoothening of edges. L*a*b color space is device independent [23].

Hanmandlu et al. (2016) used Gaussian and triangular membership functions to fuzzify the S and V component of HSV color space. The S component was modified only for overexposed images. They introduced a new entropy function and visual factor as objective function to get the optimized values of parameters used in modification of membership values using particle swarm optimization method [13].

Zhang (2016) combined the fuzzy image enhancement technique proposed by [21] with the fruit fly optimization algorithm for medical images [35]. [21] set the parameters used in fuzzification manually but here, these were optimized using fruit fly optimization algorithm. Liu et al. (2017) also used [21] technique for microscopic image enhancement of Chinese herbal medicine [19].

Membership values in type-1 fuzzy sets are crisp in nature so type-1 fuzzy sets are not able to handle uncertainties where measurements are fuzzy, parameters used to model type-1 fuzzy set are fuzzy [31]. Therefore, to handle uncertainty more complex in nature, type-2 fuzzy sets are used whose membership values are fuzzy. [3, 10, 11, 31] used type-2 fuzzy sets to enhance the images and found better results than type-1 fuzzy sets. [7–9] used intuitionistic fuzzy sets for the enhancement of grayscale images and medical images.

Sharma and Verma (2017) introduced an approach for color satellite image enhancement using a modified Gaussian and sigmoid membership function to fuzzify the V (gray level intensity) component of HSV color space. A constant function was used to defuzzify the intensity values of all the regions. Contrast assessment function proposed in [33] was used to measure the performance of the algorithm. Zhou et al. (2017) proposed a hybrid method-based using fuzzy entropy and wavelet transform for the contrast enhancement of microscopic images with an adaptive morphological approach [36].

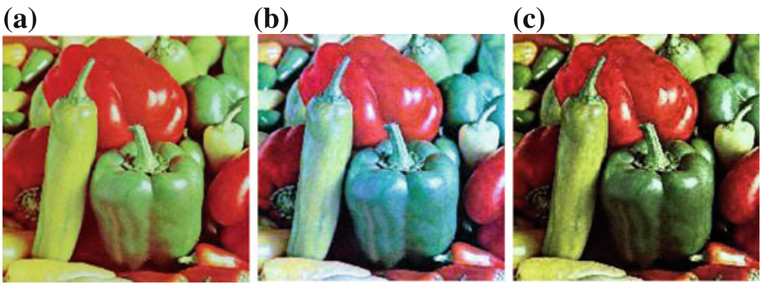

Fig. 2 **a** Original image (Peppers). **b** Enhanced image applying histogram equalization on R, G, B channels. **c** Enhanced image applying histogram equalization on V channel of HSV color space

7 Future Directions

Most of the papers used exposure (E), a crisp value, to characterize the image or images regions as overexposed ($E > 0.5$) or underexposed ($E < 0.5$). The images with exposure value 0.5 are considered as good. A fuzzy indicator should be used to distinguish the image as underexposed or overexposed.

All these techniques were designed considering one type of images. Most of the algorithms were designed considering the grayscale images and medical images. But in electronic gadgets, surveillance system, and computer vision, we deal with the color images. These algorithms cannot be generalized for all types of images, especially in the case of color images. If these algorithms are directly applied on the RGB color components, the artificial effects may rise or the color of the image may change. Image Peppers is enhanced by applying histogram equalization technique on R, G, B channels and on V channel of HSV color space after converting the RGB image into HSV color space and the natural colors of image are changed as shown in Fig. 2. A few researchers [2, 12–15, 17, 20, 23, 24, 26, 27, 32] discussed the issue of color image enhancement as per my knowledge. The work for the enhancement of images having uneven illumination is also not sorted out to the great extent.

8 Conclusion

Image enhancement is the preprocessing task in digital image processing and plays important role in human visual systems, pattern recognition, analytics, and computer vision. There are three broad categories (spatial domain, frequency domain, and fuzzy domain-based) of image enhancement. Fuzzy set is used as problem-solving tool in the systems where uncertainty and vagueness are present. Fuzzy domain-based image enhancement has three steps—fuzzification, modification of membership values, and defuzzification. The image quality is measured subjectively or objectively. Mostly, mean square error, PSNR, linear index of fuzziness, entropy, and CII are used to find the quality of an image objectively. Many researchers worked on this issue dealing with grayscale images, medical images, satellite images, and color images but a few researchers worked with the color images which are used in surveillance systems and electronic devices in our daily life. Many issues such as fuzzy indicator for the division of overexposed and underexposed region, enhancement of low contrast, and uneven illuminated images are not addressed up to a great extent. In the future work, the unaddressed issues will be solved.

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