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Noise-Free Rule-Based Fuzzy Image Enhancement

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Abstract

Different kinds of noises have considerable effects on most of image sensing systems. Suitable image contrast enhancement algorithms can improve contrast or retain detail information while reducing noises as well. Fuzzy representation of an image provides a reliable analysis when inexactness occurred at the gray level values. This paper presents a fuzzy-based novel image contrast enhancement method. Several image quality indices, such as similarity, naturalness, and mean brightness preserving examined and experimentally show the effectiveness of the proposed technique in comparison with well-known image enhancement methods such as histogram equalization and contrast limited adaptive histogram equalization methods.

Key Word*:* **Fuzzy System, Image Enhancement, Image Robustness and Naturalness, Image Quality Index.**

I-Introduction

In a wide spectrum of image processing applications, expert knowledge is used to overcome the difficulties arise because of uncertainties in data, task or results. Ambiguity and vagueness s a type of uncertainties are fuzzy in their nature. Fuzzy logic is known as a powerful tool to represent human knowledge. The fuzzy logic could be adopted as a reliable approach to handle the imperfection of imaging processing systems where problem such as whether a pixel should become darker or brighter compared to is current level or making decision about the boundary between two image segments occur.

The main objective of image enhancement is to increase the contrast of an image with a new dynamic range and bring out the hidden image details are the main objective of an image enhancement. Histogram equalization (HE) is one of the most popular schemes used for image enhancement due to its speed and simplicity of implementation [2]. An enhanced image by HE has a significantly changed brightness; therefore the output image is saturated with either very bright or dark intensity values and some annoying artifacts and unnatural enhancement are appeared. [3-5]. In order to overcome the aforementioned problems, brightness - preserving histogram equalization based techniques have been proposed.

There are several major strategies to preserve the mean brightness of HE-based image enhancement: BBHE, [6], initially decomposes an input image into two sub-images based on the separation point set to the mean intensity of the image. One sub-image is the set of samples less than or equal to the separation point whereas the other sub-image is the set of samples greater than the separation point. Then BBHE equalizes the sub-images independently based on their respective histograms [7]. DSIHE, [8], is another algorithm used to preserve the brightness of an image applying a similar procedure as BBHE but the separation point is chosen based on the median of intensity of the captured image. Similar to the mentioned schemes, two other strategies are introduced that are recursively using the same procedure. RMSHE, [9], uses BBHE recursively. It first separates the input histogram into two pieces by the mean, and then it applies this approach to each piece many times to generate (2^n-pieces) histograms. RSIHE, [10], uses similar tasks with the separation point at the median.

Fuzzy image enhancement is based on gray level mapping into membership function to generate an image of higher contrast than the original image [11]. The promising result of the fuzzy logic image enhancement accommodates some drawbacks of classical image enhancement techniques. It is capable of dealing with vague and uncertain information. In the fuzzy representation of an image, each pixel is represented by a membership function and fuzzy rules [1].

There are several image enhancement techniques base on fuzzy set theory [12]. Minimization of fuzziness or contrast intensification operator is probably is probably the first fuzzy approach reduces the amount of image fuzziness to enhance the image [12]. In the equalization using fuzzy expected value, FEV, the distance of all gray-levels to FEV is calculated to improve the image quality [12]. Histogram equalization maximizes the image information by using the entropy as an information measure [12]. Fuzzy histogram hyberbolization is the modification of histogram equalization method using suitable membership function in a logarithmic way instead of flatting it [12]. In a rule-based contrast enhancement, the parameters of the inference system are initialized, gray levels are fuzzified, inference procedure is evaluated and finally the enhanced image is achieved by the defuzzification [12]. Fuzzy relation is another image enhancement technique assuming that there is a fuzzy relation between the original and the enhanced image [12].

In this article, new fuzzy-based image enhancement as a rule based contrast enhancement is proposed. The proposed fuzzy system for the contrast enhancement is similar to the represented fuzzy structure applied in control theory for a tracking problem. It utilizes two inputs as the tracking error and its rate of variation and the output is the desired variable. Therefore the original image and a modified image constructed using a filter is applied as inputs to the introduced fuzzy image enhancement.

Simulation results show that the proposed fuzzy image enhancement algorithm has the capability to enhance images in a way that not only preserves the brightness but the artifact effect is also vanished. The rest of the paper is organized as follows: Section II proposes novel fuzzy image enhancement technique. Experimental results are explained in the section III, showing the effectiveness of the proposed fuzzy image enhancement technique compared to other alternative schemes like histogram equalization, and contrast limited adaptive histogram equalization. Finally the conclusion is presented in the section IV.

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II-Fuzzy Image Enhancement

The proposed algorithm in this article is a rule–base contrast enhancement technique. The considered fuzzy system is a two input and one output as shown in the Fig. 1.

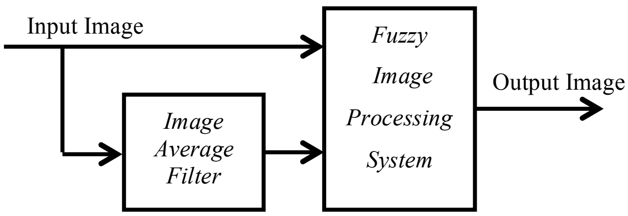

Fig.1. Fuzzy structure considered as contrast enhancement system

Captured image and the applied local average filter on it are the inputs of the fuzzy system. The membership functions assigned for each input are partitioned to the seven fuzzy set as shown in Fig. 2.

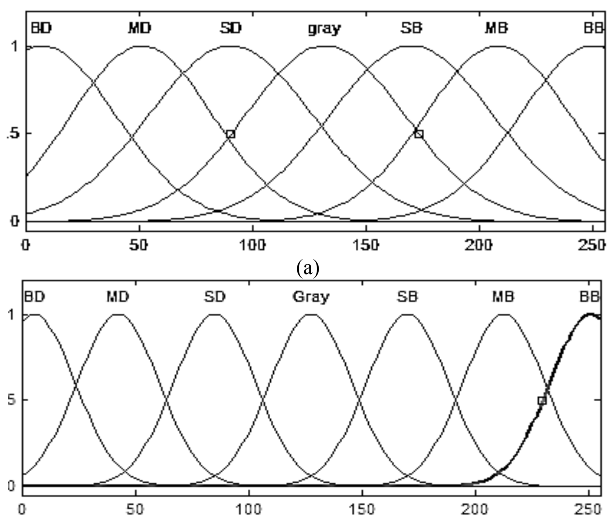

Fig.2. Membership functions of the proposed fuzzy contrast enhancement. (a) Membership function of captured image (first input), (b) membership function of filtered image (second input), and the membership function of output

The inference engine used for the proposed fuzzy enhancement system is "mamdani", max-min method and centroid as defuzzification. The fuzzy rule-base of the introduced system is borrowed from a tracking problem related to control theory as shown in table.1. The fuzzy sets abbreviation used in Table.1 are defined as:

BD	Big Dark
MD	Medium Dark
SD	Small Dark
G	Gray
SB	Small Bright
MB	Medium Bright
BB	Big Bright

The FAM table expressed in table.1 is designed in such that it preserves the brightness of the input image. There are 49 rules that partition the inputs to the seven classes defined in the table. 1.

Table. 1- Fuzzy Associated Map, FAM, of the fuzzy contrast enhancement system

	BD	MD	SD	G	SB	MB	BB
BD	BD	BD	BD	BD	MD	SD	G
MD	BD	BD	BD	MD	SD	G	SB
SD	BD	BD	MD	SD	G	SB	MB
G	BD	MD	SD	G	SB	MB	BB
SB	MD	SD	G	SB	MB	BB	BB
MB	SD	G	SB	MB	BB	BB	BB
BB	G	SB	MB	BB	BB	BB	BB

The inputs of the fuzzy system are I and ΔI which are the captured image and its average variation respectively. The output is I_e . By the mentioned definition, the fuzzy rules could be demonstrated as follows:

Fuzzy Rule Base:

If I is BD *and* ΔI is BD *then* I_e is BD
If I is BD *and* ΔI is MD *then* I_e is BD
.
.
.
If I is BB *and* ΔI is MB *then* I_e is BB
If I is BB *and* ΔI is BB *then* I_e is BB

Depending on the input image, the particular rules are fired. As the input is portioned with overlap fuzzy sets, the artifacts effect or blocking effect does not occur in the proposed enhancement technique.

III-Simulation Results

There are several tests executed in this section to verify the effectiveness of the proposed enhancement technique. The images used in this article are borrowed from [13]. Several experiment are examined to show the effectiveness of the proposed method in providing adequate enhanced images with considerably less artifacts, and to allow an appropriate and effective control over the degree and outcome of enhancement. There are some traditional issues in image enhancement, which should be evaluated for any new technique. In the following, the undesirable effect appearing on the image enhancement is considered. Using several image quality indices demonstrates that the proposed fuzzy image enhancement technique has a potential to overcome the mentioned issues.

Over Enhancement is the most common issues occurred in the image enhancement techniques. Enhancement methods usually over-enhance the background of the image while producing level saturation effects in small but visually important areas. Besides, traditional techniques often cause the average luminance of the image changes, making unwanted changes in the character of the image. In the Fig.3, a sample of over-enhancement is demonstrated. It is obvious that HE and CLAHE enhance the background of the *Splash* more and make enhanced images with more undesirable effects. Over-enhancement produces various types of issues such as: i) *Artifact Effect*, ii) *Naturalness Preserving (brightness preserving)*, and iii) *Noise-Enhanced Sensation*

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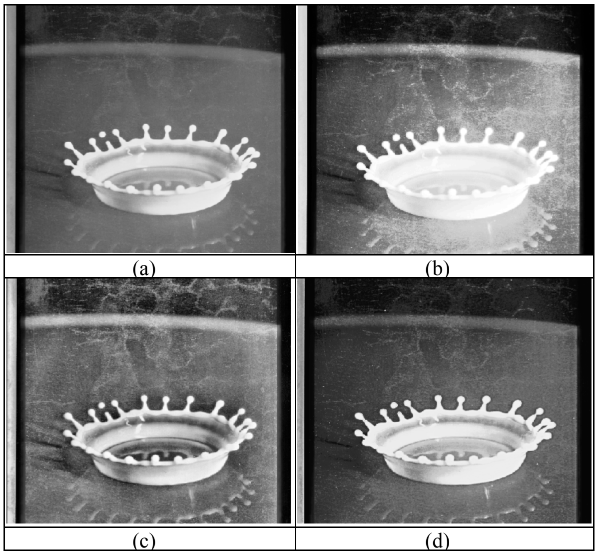

Fig.3. (a) Original Image,(b) HE, (c) CLAHE, (d) Fuzzy

Artifact Effect: Artifact effect is a common drawback of most of the existing HE-Based splitting techniques since they keep the partitioning point fixed throughout the entire process of equalization. Therefore some portions of the histogram contained in the partitions cannot be expanded much, while the outside region expands significantly which creates unwanted artifacts. In this experiment, the enhanced image by the fuzzy system is compared with the other well-known enhancement technique like HE, and, CLAHE. The results are illustrated in the Fig. 4. The unwanted artifacts appear clearly in sky region of the enhanced image by HE and CLAHE.

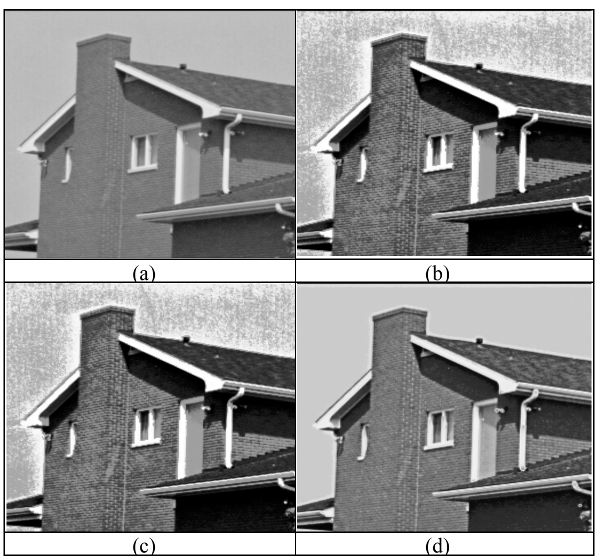

Fig.4. (a) Original Image,(b) HE, (c) CLAHE, (d) Fuzzy

Naturalness: is an important index in evaluating the Image Quality Assessment, IQM. Naturalness preservation is disadvantageous to detail enhancement in the areas of unsuitable intensity such as the dark areas. Contrast limited algorithms restrain over-enhancement by restructuring the histogram in such a way that its height does not go outside the clip limit. But, it is not easy to repair the clip limit for the images having seriously non-uniform illumination, in which the histograms of different areas have quite different naturalness [14]. The results show that the proposed fuzzy enhancement scheme is better performing as a naturalness quality compared to the HE and CLAHE. In the fig.5 there are over enhancements in (b) and (c) and therefore some artificial grayscale color are appeared. The face of the man on (c) is dark and its pants color is so bright while details about the paint on the wall and window in the Fig.5-(b) are missed. So the enhanced image in (d) is more natural.

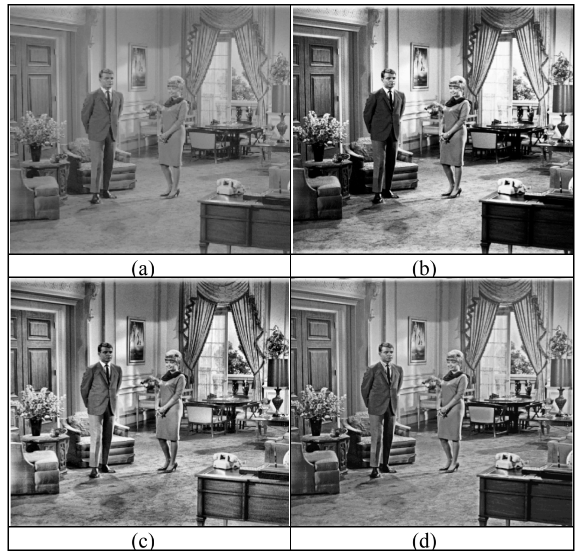

Fig.5. (a) Original Image, (b) HE, (c) CLAHE, (d) Fuzzy

Noise-Enhanced Sensation: Noise in image processing represents unwanted or undesired information that can occur during the image capture, transmission, processing or acquisition and may be dependent or independent to the image content. In Fig. 6, 5% of salt and pepper noise added to the original image
and the results illustrate that the traditional HE and CLAHE have enhanced the noise too much making the resulting image more noisy images.

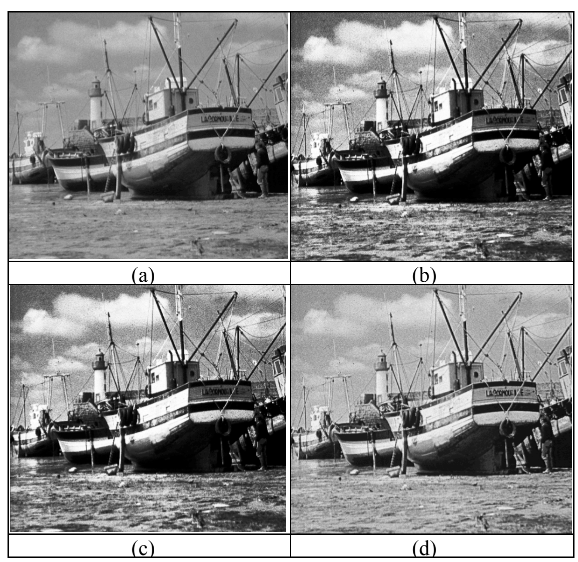

Fig.6. (a) Original Image, (b) HE, (c) CLAHE, (d) Fuzzy

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Table 2. Image enhancement data-base used in this article

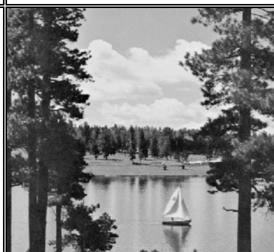
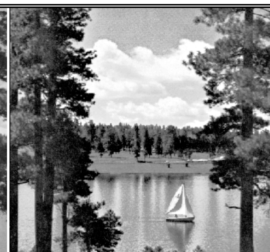
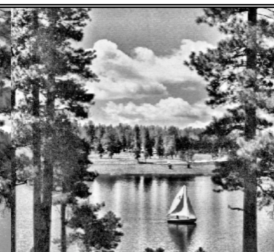
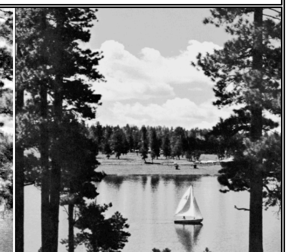
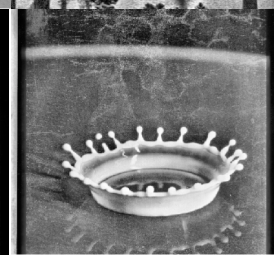
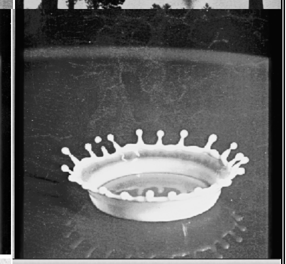
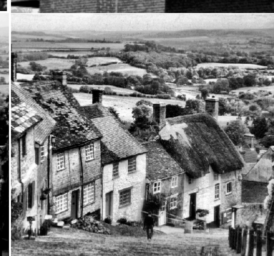
Data	Original	HE	CLAHE	Fuzzy
Boat				
Splash				
House				
Village				
Couple				

Image Quality Measurement (*IQM*)*:* Several IQMs are examined on the image database shown in table.2 such as: i) *Image Quality*, ii) *Similarity to the Original Image* iii) *PSNR* (Peak Signal to Noise Ratio), and iv) *Brightness Preserving*

Image Quality Assessment used in this article is EMEE [15]. The description of the mentioned index is:

$$EMEE = (\frac{1}{k_1 k_2}\sum_{l=1}^{k_2}\sum_{k=1}^{k_1}\frac{I^{\omega}_{max;k,l}}{I^{\omega}_{min;k,l}}\log\frac{I^{\omega}_{max;k,l}}{I^{\omega}_{min;k,l}})$$

where, $I^{\omega}_{max;k,l}$and $I^{\omega}_{min;k,l}$respectively are the minimum and maximum values of the image $x(n,m)$ inside the block$\omega_{k,l}$. The results are stated in Table.3.

Table. 3-Image Quality Enhancement, EMEE[15]

EMEE[15]	Original	HE	CLAHE	Fuzzy
Boat	0.5355	0.8693	0.6808	0.8960
Splash	0.5281	0.5279	0.4785	0.6901
House	0.5117	0.6896	0.6054	0.7311
Village	0.7502	0.7096	0.7858	0.8621
Couple	0.3312	0.7211	0.6964	0.6940

In most cases, fuzzy enhancement technique provides better quality than the others, table.3. *Similarity to the Original Image*: To find the effectiveness of the proposed method, Similarity Index is also calculated.

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The Similarity Index is Structural-Similarity; SSIM [16] defined as:

$$SSIM = [l(x, y)]^{\alpha} [c(x, y)]^{\beta} [s(x, y)]^{\gamma}$$

where *l*, *c*, and *s* stand for luminance, contrast, and structure between the enhanced image and the original image respectively. α, β and γ are parameters used to adjust the relative importance of the three components. The definition for each function is represented in [16]. The results of applying the SSIM assessment to the provided database are demonstrated in Table.4. The results show the superiority of the proposed image enhancement technique over HE and CLAHE.

Table.4 Similarity Measurement, SSIM, [16]

Similarity[16]	HE	CLAHE	Fuzzy
Boat	0.5659	0.5418	0.7280
Splash	0.6614	0.6075	0.7445
House	0.3498	0.3769	0.6390
Village	0.7255	0.6201	0.8315
Couple	0.4182	0.4212	0.4501

PSNR is a measure that shows how much the enhancement schemes could overcome the noise effect. The PSNR equation is: $PSNR = 10log_{10}\left(\frac{peakval^2}{MSE}\right)$, where MSE is the mean square error between the original and enhanced image. The results are provided in Table.5.

Table.5-PSNR-Image Quality Index

PSNR	HE	CLAHE	Fuzzy
Boat	20.012	16.55	20.50
Splash	15.83	17.94	22.09
House	16.99	16.75	21.73
Village	16.76	15.45	21.68
Couple	15.27	16.48	19.43

The outcome corresponding to the proposed method performs better in the case that the original image is included in some kind of noises.

Brightness-Preserving: To figure out how much the brightness changes by any image enhancement techniques, the difference between the mean of the enhanced and original image is calculated. The results are represented in the Table. 6.

Table 6. Mean Difference of original and Enhanced image

Mean	HE	CLAHE	Fuzzy
Boat	1.94	10.42	1.74
Splash	24.45	9.76	7.63
House	11.69	11.09	0.94
Village	14.7	16.98	6.25
Couple	3.44	5.79	2.81

The results show that the proposed enhancement scheme could better preserve the brightness of the original image.

IV-Conclusion

The proposed method provides enhanced images with significantly fewer artifacts and allows an appropriate and effective control over the degree of enhancement. Robustness to the noise, constructing a more natural enhanced image and generating an image with more similarity to the original one are the main advantages of the proposed fuzzy enhancement technique.

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