IMPROVING IMAGE CONTENTS USING FUZZY RULE-BASED CONTRAST ENHANCEMENT AND HISTOGRAM EQUALIZATION: A COMPARATIVE STUDY

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ABSTRACT: Contrast enhancement is a well known technique used as an image enhancement task in a digital image processing system. The enhanced output image has improved visual contents, as compared to the input image, to better suite an application. Histogram equalization is commonly used in the spatial domain to accomplish the same task. Fuzzy rule-based systems are used to employ domain expert knowledge in the form of if-then rules. These systems are capable to address problems having an element of uncertainty. In this paper, a fuzzy rule-based system is implemented for image contrast enhancement with three simple rules. A set of standard digital images from public domain are used to generate results from the developed expert system. Global histogram equalization is applied to image data set for comparison. The comparative analysis show superior visual contents in the case of fuzzy rule-based approach as compared to the spatial domain histogram equalization technique. The assessment methods include correlation, mutual information, structural similarity index, structural similarity index with automatic downsampling, and natural image quality evaluator.

Keywords: Fuzzy rule-based contrast enhancement, histogram equalization, image quality assessment

INTRODUCTION

Image enhancement refers to a set of techniques used to generate a better representation of an input image. The output image has improved visual content as compared to the input image for use in a better way within a specific application. Despite many research efforts in digital image processing discipline, the theory of image enhancement is not well established [1]. In spatial domain, histogram equalization is commonly used for the contrast enhancement task. Histogram processing is also useful for compression and segmentation. An image with a low contrast has a narrow image histogram as shown in Fig. 1. In this case, the intensity levels of image is adjusted from range [7 255] to [63 191] to produce a low contrast image.

The intensity level of a pixel in an image, called a digital number, and may be considered as a random variable. The probability of occurrence of intensity level r_k is approximated as

$$p_r(r_k) = \frac{n_k}{MN}$$

where n_k is the number of pixels with intensity r_k, MN is image size, and k = 0, 1, …, L – 1. Here L represents number of intensity levels. A histogram equalized image, as shown in Fig. 2, is obtained by the following transformation which maps each pixel from input image to output image with a new intensity level s_k.

$$s_k = \frac{L-1}{MN}\sum_{j=0}^{k} n_j$$

New intensity levels spread across the whole gray scale improving visual contents as a result of this transformation.

A fuzzy rule-based contrast enhancement system, as shown in Fig. 3, has following five steps [2]: fuzzify inputs, apply fuzzy operator, apply implication method, aggregate all outputs, and defuzzify. An example fuzzy rule-based system for contrast enhancement is described in [1] from [3]. This example is implemented in Matlab with a typical selection of membership functions in [4] as shown in Fig. 4. The input linguistic variable, called "intensity," can have three values which are dark, gray, and bright. The output linguistic variable, called "newintensity," can have three values which are darker, gray, and brighter. The rules are:

IF a pixel is dark, THEN make it darker.
IF a pixel is gray, THEN make it gray.
IF a pixel is bright, THEN make it brighter.

Figure 5 shows the output image when fuzzy-rule based contrast enhancement is applied on the input image in Fig. 1. The histogram here is given for comparison with equalized image in Fig. 2. The spread of intensity values in fuzzy rule-based contrast enhancement has a different pattern as compared to the spread of intensity values in histogram equalization. The image histogram here is more like the histogram of input image in Fig. 1.

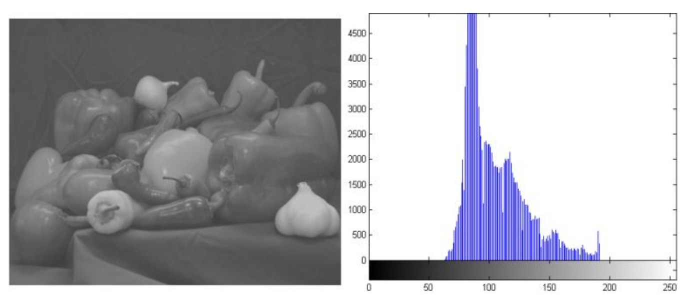

Fig. 1 Example of a low contrast image and histogram.

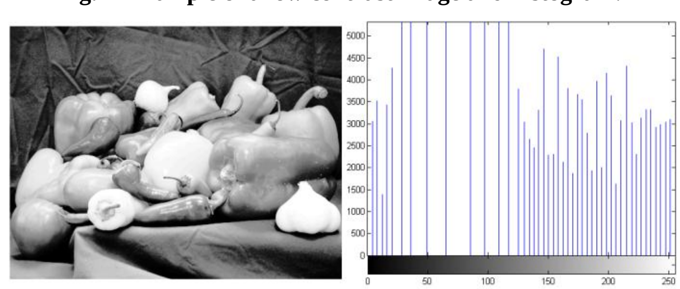

Fig. 2 Histogram equalized image and histogram.

BREIF LITERATURE REVIEW

Image enhancement techniques are generally classified in spatial domain or frequency domain, however, fuzzy-based contrast enhancement techniques offer another promising alternative. Fuzzy sets theory and logic operations are capable to perform computations in linguistics values [5-7]. Fuzzy logic operations are used to manipulate digital images, including the image enhancement task [8-14].

A number of fuzzy-based image enhancement techniques are described in [3]: λ-enhancement, equalization using fuzzy expected value, hyperbolization, minimization of fuzziness, rule-based approach, and enhancements using fuzzy relations. "The fuzzy-rule based approach is a powerful and universal method" which is successfully used in digital image processing applications [3]. Recently reported techniques in research literature include image enhancement using fuzzy sure entropy, interval type II fuzzy sets, and intuitionistic fuzzy sets theory [15–17].

Histogram equalization is the mostly used method for image enhancement due spatial domain, statistics-based technique and ease in implementation in both hardware and software. The procedure increases the dynamic range of gray levels that results in contrast enhancement [1]. Contrast enhancement is a low-level image processing task as the output is also an image. Recent techniques in research literature that used and improved histogram equalization technique are visual contrast enhancement algorithm and contrast enhancement algorithm based on gap adjustment for histogram equalization [18,19]. In this study , a comparison of global histogram equalization technique and a typical implementation of fuzzy rule-based contrast enhancement technique [4] is presented.

MATERIAL AND METHODS

Matlab is used as a standard technical computing environment for experimentation with a selected image dataset, See Tab. 1. Global histogram equalization built-in Matlab function is used. Fuzzy Toolbox is used to implement typical fuzzy rule-based contrast enhancement system as described in [1] using input and output membership functions from [4].

Image quality assessment (IQA) to compare performance of contrast enhancement techniques is important. Selected IQA methods in this study are correlation (CORR), mutual information (MI), structural similarity (SSIM) index [20], SSIM with automatic downsampling (SSIMd), and natural image quality evaluator (NIQE) [21].

RESULTS AND DISCUSSION

Figure 6 shows selected standard input, histogram equalized, and fuzzy rule-based contrast enhanced images. The standard images information and assessment results are summarized in Tab. 1 and Tab. 2, respectively. All standard input images are converted to portable network graphics format.

In the case of CORR assessment method, all enhanced images using fuzzy rule-based contrast enhancement, in column FUZZ, have better results except for the skeleton input image. The MI assessment method results show improvements for CT, Einstein, and peppers. The SSIM assessment method results show improvements for all images except the lake image. Same is shown by the SSIMd results. The NIQE assessment method results show improvements in Einstein and lake images with histogram equalization, in column HIST, and in lake and skeleton images with fuzzy rule-based contrast enhancement. Whereas, the input images, in column INPUT, CT, house, and peppers have better NIQE index values as compared to those in both HIST and FUZZ.

The results from CORR, SSIM, and SSIMd assessment methods show improvements in visual contents for fuzzy-rule base contrast enhancement. However, the results from MI and NIQE assessment methods show mixed results as stated earlier. The MI measures the information quantity to obtain intensity value sk from rk. A higher MI value means a stronger dependency. The NIQE is a measure based on a natural scene statistic model. An interesting assessment result in this context is for the skeleton image. A lower value of MI measure suggested a lower dependency whereas a high value of NIQE measure suggested otherwise. In one dimension, these spatial domain image quality assessment methods need further exploration and may not be directly applicable to measure the quality of enhanced images. In another dimension, NIQE index needs to be train through a different (non-)natural scene statistic model.

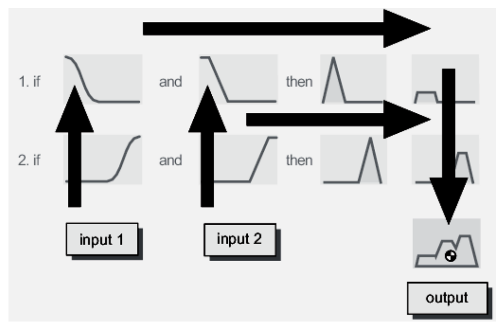

Fig. 3 Fuzzy inference process [2].

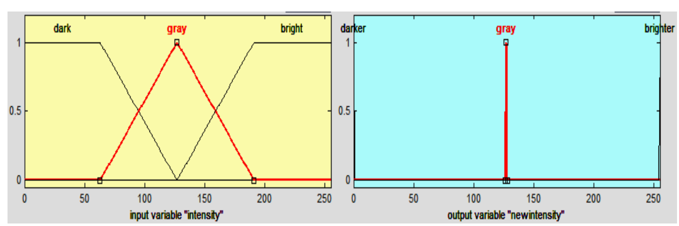

Fig. 4 Input and output membership functions for fuzzy rule-based contrast enhancement [4].

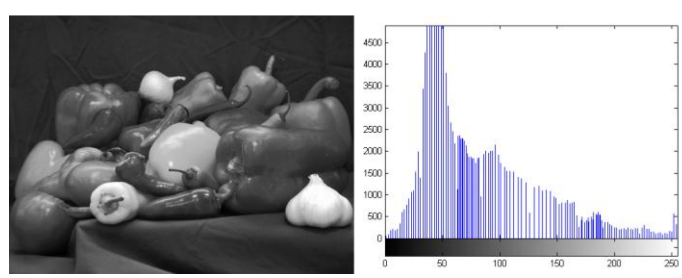

Fig. 5 Result of fuzzy rule-based contrast enhancement: output image and histogram.

Tab.1 Standard image data set.

Image	Width	Height	Bit depth	Size
CT	570	600	8	81,792
Einstein	490	600	8	129,658
House	512	512	8	85,598
Lake	512	512	8	172,011
Skeleton	500	800	8	116,819
Peppers	512	384	8	73,086

Tab.2 Image quality assessment results.

Image	CORR		MI		SSIM		$SSIM_d$		NIQE		
	HIST	FUZZ	HIST	FUZZ	HIST	FUZZ	HIST	FUZZ	INPUT	HIST	FUZZ
CT	.9396	.9860	3.1466	3.1907	.4147	.9056	.4428	.9172	6.0044	**5.8868**	**5.8642**
Einstein	.7283	.9969	3.8564	4.2833	.2364	.8442	.2604	.8486	4.0392	5.5262	**3.9995**
House	.9733	.9899	4.5728	**4.4729**	.6646	.7679	.7124	.7867	6.6132	**5.9088**	**6.4417**
Lake	.9854	.9866	5.9357	**4.6717**	.8473	**.5937**	.8972	**.6447**	4.1028	4.2314	4.5636
Skeleton	.8741	**.7949**	3.9433	**0.8207**	.1091	.5405	.1165	.5088	4.8546	**4.2672**	19.2905
Peppers	.8958	.9950	5.3180	6.0199	.4731	.7793	.4630	.7688	6.2299	**3.5434**	**4.8368**

(Assessment method spans CORR through NIQE.)

Fig. 6 (From top row to bottom) standard input images, histogram equalized images, and output of fuzzy rule-based contrast enhancement.

CONCLUSIONS

In this paper, a comparative analysis of two important image enhancement techniques is presented. These image enhancement techniques include histogram equalization and fuzzy rule-based contrast enhancement. Both techniques are applied on a standard image dataset to output enhanced images with improved visual contents. The results from correlation, structural similarity index, and structural similarity with down sampling index image quality assessment methods have suggested overall better results for fuzzy rule-based contrast enhancement. However, results from mutual information and natural image quality evaluator index have suggested mixed results. Future directions of research are to compare recent fuzzy contrast enhancement techniques with recent image quality assessment methods and to develop a more suitable image quality assessment measure for enhanced output images.

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