Image Enhancement Method based on an Improved Fuzzy C-Means Clustering

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***Abstract*—Image enhancement is an important method in the process of image processing. This paper proposes an image enhancement method base on an improved fuzzy c-means clustering. The method consists of the following steps: firstly, proposed a fuzzy c-means clustering with a cooperation center(FCM-co). Secondly, using the FCM-co, divide the image pixels into different clusters and marked membership values to those clusters. Thirdly, modify the membership values. Finally, calculate the new pixel gray levels. This enhancement method can overcome the disadvantage of overexposure and better retain image details. Through the experiment, the test results show that the proposed enhancement method could achieve better performance.**

***Keywords*—Image enhancement; fuzzy clustering; fuzzy c-means clustering; membership; objective function**

I. Introduction

Image enhancement plays a significant role in digital image processing. Low contrast in digital images can result from many circumstances, including lack of sunlight or indoor lighting, and inadequacy of the device. There are many methods to enhance images. Histogram equalization (HE) is the simplest image enhancement method. It stretches the histogram of the image, based on the probability probability density function and cumulative distribution function values of the pixels, leading to enhancement in the contrast of the image [1], [2], [3], [4], [5]. The gamma correction-based method is an automatic transformation technique that improves the brightness of dimmed images via the gamma correction and probability distribution of luminance pixels, this method uses temporal information regarding the differences between each frame to reduce computational complexity [6], [7], [8]. Fuzzy sets can deal with some uncertain factors better than classical mathematics. Fuzzy technology is also increasingly used for image processing [9], [10], [11].

In 2000, H.D. Cheng et.al proposed a novel adaptive direct fuzzy contrast enhancement method based on the fuzzy entropy principle and fuzzy set theory [12]. In 2009, M. Hanmandlu et.al presented a new approach for the enhancement of color images using the fuzzy logic technique [13]. In 2011, G. Li et.al proposed an image enhancement operation that used the value of grey entropy in the neighborhood window as parameters to measure the level of the current pixel being edge point [14]. In 2012, K. Hasikin et.al presented a fuzzy gray scale enhancement technique for low contrast image [15]. In 2016, A. K. Gupta et.al presented a fuzzy based enhancement technique for low contrast gray scale image [16]. In 2017, V. Magudeeswaran et.al presented a Contrast limited fuzzy adaptive histogram equalization to improve the contrast of MRI Brain images [17]. In 2019, S. Zenian et.al implemented an intuitionistic fuzzy set and fuzzy set, respectively, in the fEEG image by using intensification operator in enhancing the contrast of the image [18], [19].

The fuzzy c-means (FCM) clustering algorithm was first introduced by Dunn [20] and later extended by Bezdek [21]. FCM clustering algorithm is often used to deal with data classification problems. In recent years, it has been applied to image processing [22]. The main idea of the algorithm is to divide the data set into different categories by calculating the difference between gray values and clustering center iteration, so as to optimize the criterion function for evaluating clustering performance.The algorithm is an iterative clustering method that produces an optimal partition by minimizing the weighted within group sum of the squared error objective function.

This paper proposed an image enhancement method base on an improved fuzzy c-means clustering (FCM-co). Compared with the traditional fuzzy C-means clustering, FCM-co has a cooperation center. The data used in cooperation center calculate is a cooperation matrix of the same size as the image. The cooperation matrix element value is the average of the gray values of the pixel at the corresponding image position and the pixels around it. This means that FCM-co also considers the image pixels' location information. In the clustering process, the cooperation center is always updated synchronously with the clustering center. After the FCM-co divides the image pixels into different clusters and marks pixels' membership value, we modify the pixels' membership value again and calculate the pixels' new gray levels. The paper's contribution is to propose a new clustering method(FCM-co) and a new function to modify the membership value. In the last section, the test results show that this paper proposed an enhancement method that could achieve better performance.

II. Methodology

A. Improve Fuzzy C-Means Clustering

Compared with traditional clustering methods, in order to better use the position information of pixels in the image, this paper proposes a fuzzy c-means clustering with a cooperation center (FCM-co). The FCM-co's objective function as follows:

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$$J_m = \sum_{i=1}^{c}\sum_{j=1}^{N} u_{ij}^m \left(\|x_j - v_i\|^2 + \alpha \left\|x_j^* - v_i^*\right\|^2\right). \quad (1)$$

Image $I = \{x_{k,p}|k = 1, 2, 3, \cdots, m, p = 1, 2, 3, \cdots, n\}$, where $x_{k,p}$ is the gray scale of the pixel in row k and column p of the image. $I^* = \{x^*_{k,p}|x^*_{k,p} = mean(x_{k,p}$ and around $x_{k,p})\}$ is the cooperation matrix of Image I. In the Eq. (1), $X = \{x_j|x_j = x_{k,p}, j = (k-1)n+p$, $1 \leq$ k $\leq$ m, $1 \leq$ p $\leq$ n, $x_{k,p} \in I\}$, similarly, $X^* = \{x^*_j|x^*_j = x^*_{k,p}, j = (k-1)n + p$, $1 \leq$ k $\leq$ m, $1 \leq$ p $\leq$ n, $x^*_{k,p} \in I^*\}$, $N = mn$. c is the number of clusters. u_{ij} is the degree of membership of x_j and x^*_j in ith cluster, m is the weighting exponent on each fuzzy membership, v_i and v^*_i are the prototype of the center of cluster i, $\|x_j - v_i\|^2$ is a distance measure between object x_j and cluster center v_i, $\left\|x^*_j - v^*_i\right\|^2$ is a distance measure between object x^*_j and cluster center v^*_i. The parameter α is a constant. By definition, each point x_j satisfies the constraint that $\sum_i^c u_{ij} = 1$. The object function J_m can be obtained through an iterative as follows:

Step A : Initialize the membership values u_{ij}.

Step B : Calculate the v_i and v^*_i by

$$v_i = \frac{\sum_{j=1}^{N} u_{ij}^m x_j}{\sum_{j=1}^{N} u_{ij}^m}, \quad (2)$$

and

$$v^*_i = \frac{\sum_{j=1}^{N} u_{ij}^m x^*_j}{\sum_{j=1}^{N} u_{ij}^m}. \quad (3)$$

Step C : Update u_{ij}

$$u_{ij} = \sum_{k=1}^{c}\left(\frac{\|x_j - v_i\|^2 + \alpha\left\|x^*_j - v^*_i\right\|^2}{\|x_j - v_k\|^2 + \alpha\left\|x^*_j - v^*_k\right\|^2}\right)^{-\frac{1}{m-1}}. \quad (4)$$

Step D : Compute the value of the objective function $J_m^{(t)}$

$$J_m^{(t)} = \sum_{i=1}^{c}\sum_{j=1}^{N} u_{ij}^m \left(\|x_j - v_i\|^2 + \alpha \left\|x_j^* - v_i^*\right\|^2\right). \quad (5)$$

Step E : If $\left|J_m^{(t)} - J_m^{(t-1)}\right| < \epsilon$, then stop. Otherwise, $t = t + 1$, return to step B.

B. Modify Membership and Calculate New Gray Scale Level

After FCM-co marks the membership value for pixels, for further adjust pixels' the membership value, we propose the following adjustment function:

$$u^*_{ij}(x_j) = \begin{cases} u_{ij}(x_j), & x_j \leq \hat{v}_{i=1,2,\cdots,c} \\ 1 + \frac{1-u_{ij}(x_j)}{2}, & x_j > \hat{v}_{i=1,2,\cdots,c} \end{cases}. \quad (6)$$

In the Eq.(6), $j = 1, 2, 3, \cdots, N$. $u^*_{ij}(x)$ is the modified membership of the jth pixel in the ith cluster. $\hat{v}_i$ is the cluster, $\hat{v}_i$=max(v_i, v^*_i).

For calculation of the new gray scale level of the pixel, the original image gray scale levels are updated and mapped to compute the enhanced image by given formulations:

$$y_j = \frac{1}{c}\sum_{i=1}^{c} u^*_{ij}(x_j)x_j, \quad j = 1, 2, \cdots, N. \quad (7)$$

Where y_j is the new gray scale level of the jth pixel.

C. Algorithm

This paper uses the algorithm to process the test images as follows:

Step 1: Initialize the parameters: m, c, α, and ϵ.

Step 2: Calculate the cluster centers and pixels' membership value using FCM-co, Eqs.(2)-(5).

Step 3: Modify the membership values using Eq.(6).

Step 4: Calculate the new pixels' gray scale level using Eq.(7).

III. Experimental Results and Analysis

In this section, when we use the algorithm in the experiment, set the the parameters $m = 2, c = 2, \alpha = 1$, and $\epsilon = 0.00001$.

A. Subjective Analysis

There show the effect of the proposed method on image enhancement (see Fig. 1). To analyze the performance, the proposed method is compared with methods in [23], [24], and [25] (see Fig. 2).

Fig. 1. Original and Result Images.(a) Original, (b) Enhanced by Proposed Method.

Fig. 1 shows that the proposed method can enhance the image. In Fig. 2(b), and Fig. 2(d), the layered highland, signage, door inside the courtyard wall, and house in the distance are not visible. It overexposed the image and lost some image details. Although Fig. 2(c) retains more image details,

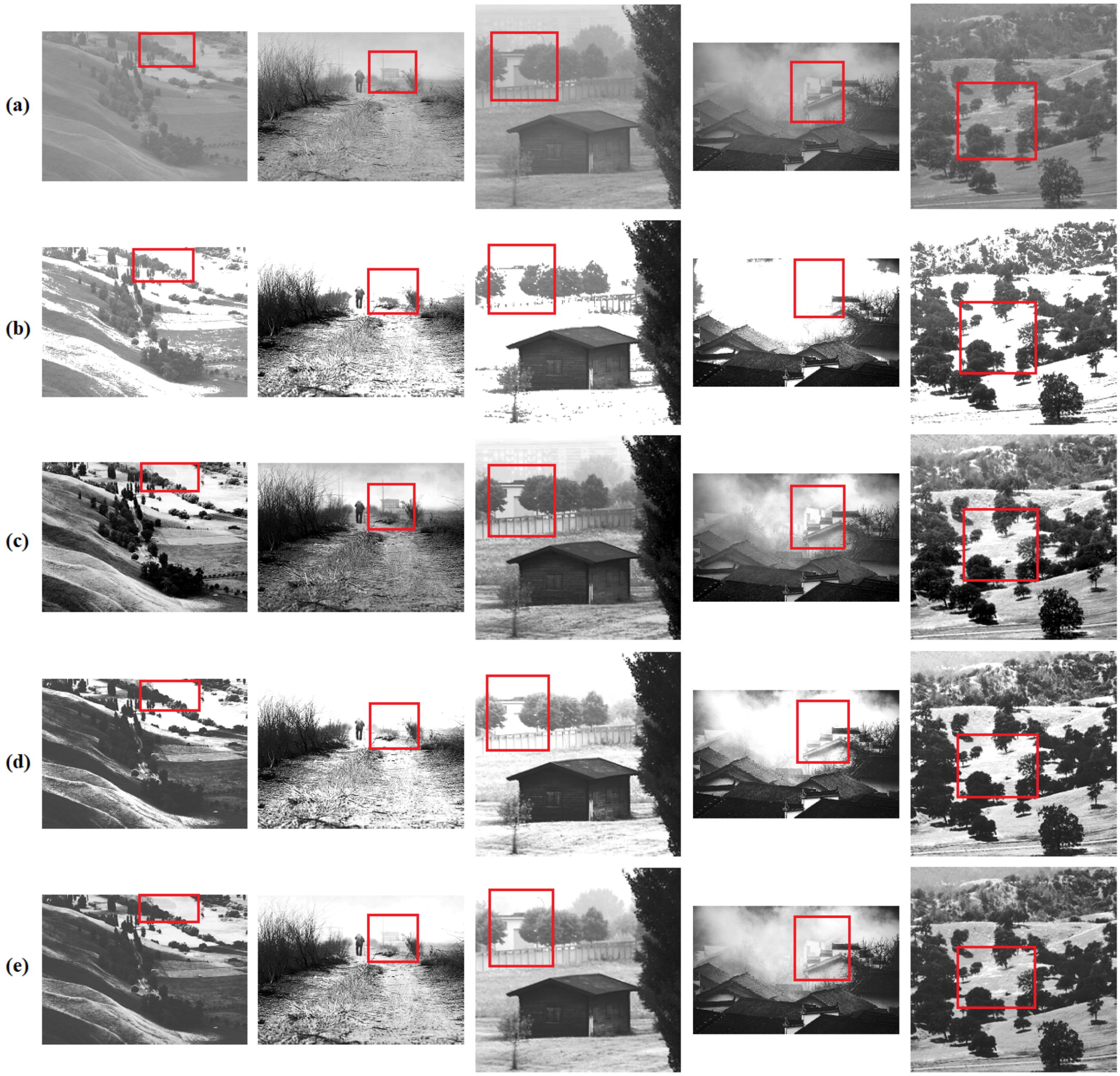

Fig. 2. Original and Result Images. (a) Original, (b), (c) and (d) are Enhanced by Methods in [23], [24], and [25], Respectively, (e) Enhanced by Proposed Method.

it also has the disadvantage of insufficient enhancement. The image details retained by Fig. 2(e) are similar to those of Fig. 2(c), such as layered highland, signage, door inside the courtyard wall, and house. But the image contrast of Fig. 2(e) is higher than that of Fig. 2(c). Through visual contrast, Fig. 2(e) (processed by the proposed method) can increase the image contrast, be fully exposed, and also retain some obvious image details.

B. Objective Analysis

For image enhancement effect evaluation, this paper used algorithms include mean squared error(MSE), peak signal-noise ratio(PSNR), structural similarity(SSIM), average gradient(AG), Linear index of fuzziness(IOF) and entropy[26], [27]. The lower MSE(IOF) or the higher PSNR(SSIM, AG, entropy) indicates a better enhancement effect.

$$MSE = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} (x_{i,j} - y_{i,j})^2. \tag{8}$$

$$PSNR = 10 \times \log_{10} \frac{(2^n - 1)^2}{MSE} dB. \tag{9}$$

TABLE I. MEAN SQUARED ERROR (MSE) TEST RESULTS

Image \ Method	in [24]	in [23]	in [25]	Proposed
APC	3319.11	10067.11	3965.29	**1029.43**
Aerial	**1157.93**	2952.3	2401.57	1875.44
Aerial2	4724.8	1990.49	2600.87	**1691.43**
Airplane (U-2)	12512.85	9470.55	358.98	**197.05**
Airplane	6636.69	**1403.04**	2325.95	2059.08
Airplane2	6171.68	3240.9	5274.58	**1923.66**
Airport	3929.97	7638.73	1462.95	**802.09**
Car and APCs	2222.48	8356.03	3081.27	**875.94**
Car and APCs2	2604.8	7992.16	2987.44	**1015.41**
Chemical plant	1758.64	7479.43	2158.83	**852.43**
Clock	4692.85	1325	1391.97	**1190.81**
Couple	1553.43	6338.95	2794.77	**1008.98**
Fishing Boat	1305.72	6892.04	3759.02	**1097.29**
Male	1818.22	7950.11	2110.15	**656.78**
Moon surface	2552.64	6804.04	3166.42	**1280.56**
Stream and bridge	**741.44**	4422.23	1811.54	1151.65
Tank	2724.2	7717.86	3971.38	**1175.79**
Tank2	3148.4	9525.06	2327.63	**919.98**
Tank3	1638.34	6282.33	3529.53	**1298.46**
Truck and APCs	2098.07	8009.45	2368.24	**883.67**
Truck and APCs2	3165.58	9909.88	1786.73	**653.02**
Truck	2915.86	10696.75	2598.83	**857.2**

TABLE II. PEAK SIGNAL TO NOISE RATIO (PSNR) TEST RESULTS

Image \ Method	in [24]	in [23]	in [25]	Proposed
APC	12.9206	8.1018	12.1481	**18.0048**
Aerial	**17.4940**	13.4292	14.3258	15.3998
Aerial2	11.3870	15.1412	13.9796	**15.8483**
Airplane (U-2)	7.1572	8.3671	22.5802	**25.1850**
Airplane	9.9113	**16.6601**	14.4648	14.9941
Airplane2	10.2268	13.0241	10.9089	**15.2895**
Airport	12.1869	9.3006	16.4785	**19.0886**
Car and APCs	14.6624	8.9108	13.2435	**18.7061**
Car and APCs2	13.9731	9.1042	13.3778	**18.0644**
Chemical plant	15.6790	9.3921	14.7886	**18.8242**
Clock	11.4164	16.9086	16.6945	**17.3724**
Couple	16.2179	10.1106	13.6673	**18.0920**
Fishing Boat	16.9723	9.7473	12.3801	**17.7276**
Male	15.5343	9.1271	14.8877	**19.9566**
Moon surface	14.0609	9.8031	13.1251	**17.0568**
Stream and bridge	**19.4300**	11.6744	15.5503	17.5176
Tank	13.7784	9.2558	12.1414	**17.4275**
Tank2	13.1499	8.3421	14.4617	**18.4930**
Tank3	15.9868	10.1496	12.6536	**16.9965**
Truck and APCs	14.9126	9.0948	14.3865	**18.6679**
Truck and APCs2	13.1263	8.1701	15.6102	**19.9815**
Truck	13.4831	7.8383	13.9830	**18.8000**

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}. \tag{10}$$

$$AG = \frac{1}{(M-1)\times(N-1)}\sum_{i=1}^{M-1}\sum_{j=1}^{N-1}\sqrt{\frac{(x_{i,j}-x_{i+1,j})^2 + (x_{i,j}-x_{i,j+1})^2}{2}}. \tag{11}$$

$$IOF = \frac{2}{M\times N}\sum_{i=1}^{M}\sum_{j=1}^{N} min(u_{ij}^{'}, 1-u_{ij}^{'}). \tag{12}$$

In Eq. (9), $n = 8$ (the test image are 8bit image). In equation (10), 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[28]. In Eq. (12), $u_{ij}^{'}$ is membership value. For experimentation, we considered 22 images from Miscellaneous(MISC) dataset (http://sipi.usc.edu/database/dat abase.php?volume=misc).

As shown in Tables I, II, and III, except for test image 'Aerial', 'Airplane', and 'Stream and bridge', the proposed method achieves a lower MSE value, and a higher PSNR and SSIM value. Table IV shows that in more than half of the test images, the proposed method obtained a higher PSNR value. In Table V, compared to the original test images, all the result images have a lower IOF value, and More than half of the result images achieve a higher entropy value. The above experimental results show that the proposed method has a good enhancement effect.

TABLE III. STRUCTURAL SIMILARITY (SSIM) TEST RESULTS

Image \ Method	in [24]	in [23]	in [25]	Proposed
APC	0.3585	0.4292	0.7818	**0.8963**
Aerial	**0.8055**	0.6303	0.6823	0.7630
Aerial2	0.6148	0.7503	0.7309	**0.7966**
Airplane (U-2)	0.1946	0.3386	0.8051	**0.8148**
Airplane	0.5667	**0.8589**	0.8027	0.8421
Airplane2	0.3827	0.6809	0.8653	**0.9411**
Airport	0.6645	0.5493	0.7504	**0.8119**
Car and APCs	0.5977	0.4896	0.7244	**0.8392**
Car and APCs2	0.5234	0.4578	0.6266	**0.7468**
Chemical plant	0.7740	0.4812	0.6999	**0.8096**
Clock	0.5808	0.8662	0.8690	**0.8916**
Couple	0.7042	0.5386	0.6924	**0.8006**
Fishing Boat	0.7017	0.5770	0.7870	**0.8917**
Male	0.8412	0.5518	0.8182	**0.8862**
Moon surface	0.5188	0.4498	0.5805	**0.7448**
Stream and bridge	**0.8851**	0.5854	0.7310	0.7992
Tank	0.4418	0.5170	0.6944	**0.8216**
Tank2	0.5034	0.3922	0.5727	**0.6836**
Tank3	0.6819	0.5882	0.7069	**0.8080**
Truck and APCs	0.6861	0.4794	0.6629	**0.7697**
Truck and APCs2	0.6718	0.4302	0.6987	**0.7985**
Truck	0.5795	0.4567	0.6905	**0.8044**

TABLE IV. AVERAGE GRADIENT (AG) TEST RESULTS

Image \ Method	no processed	in [23]	in [24]	in [25]	Proposed
APC	5.7959	11.4499	8.2862	23.6886	**30.4575**
Aerial	16.3869	30.7155	25.6089	**30.8756**	27.5800
Aerial2	12.3869	20.1639	19.4104	21.2859	**25.3468**
Airplane (U-2)	6.0065	5.5144	4.4803	32.7717	**40.3657**
Airplane	4.1840	6.5466	5.5092	6.2647	**8.5707**
Airplane2	3.3934	3.3481	4.8411	10.1661	**19.2798**
Airport	11.1810	19.7410	14.5196	**28.9451**	26.4079
Car and APCs	6.3992	13.9373	9.8210	16.9770	**17.2540**
Car and APCs2	6.5654	17.3508	11.6941	**20.7892**	20.2743
Chemical plant	12.1112	23.8362	17.8722	**27.8279**	21.8129
Clock	6.9641	9.2652	7.8369	9.4388	**9.9800**
Couple	8.2969	16.6550	12.4401	**18.7798**	16.4511
Fishing Boat	9.3853	15.4133	12.7929	15.6537	**20.3534**
Male	7.9166	11.6793	9.5091	**11.9637**	10.6810
Moon surface	8.5623	24.0696	15.3094	25.0325	**25.5287**
Stream and bridge	14.5846	21.9104	16.7949	**27.7772**	21.0173
Tank	7.3563	16.9021	11.5328	19.5906	**28.0855**
Tank2	9.6327	27.8177	18.1442	**37.5682**	32.0589
Tank3	9.1506	17.7282	12.5414	16.6483	**20.3116**
Truck and APCs	10.6206	24.9340	17.0698	**30.2223**	23.6833
Truck and APCs2	10.5282	22.8365	15.8909	**32.4396**	24.2075
Truck	6.8949	15.4893	10.8829	19.9877	**20.4818**

IV. CONCLUSION

This paper proposed an image enhancement method base on an improved fuzzy c-means clustering(FCM-co). The FCM-co has a cooperation center and it could consider image pixels' location information. The paper introduces a new function to modify the membership value. Through comparative experiments, the results show that the proposed method has a good

TABLE V. LINEAR INDEX OF FUZZINESS (IOF) AND ENTROPY TEST RESULTS

Image	IOF		Entropy	
	Original	Proposed	Original	Proposed
APC	0.7640	**0.6601**	5.0534	**5.5069**
Aerial	0.6868	**0.4045**	**7.3118**	6.8089
Aerial2	0.5362	**0.2484**	**6.9940**	6.0122
Airplane (U-2)	0.2751	**0.1507**	**5.6415**	4.9032
Airplane	0.3137	**0.2481**	**6.4523**	5.0018
Airplane2	0.5756	**0.2566**	4.0045	**4.3660**
Airport	0.6210	**0.4144**	**6.8303**	6.7218
Car and APCs	0.7875	**0.6152**	6.1074	**6.8027**
Car and APCs2	0.7743	**0.6124**	5.9088	**6.8092**
Chemical plant	0.6534	**0.4826**	7.3424	**7.4994**
Clock	0.3552	**0.1479**	**6.7057**	4.1180
Couple	0.7660	**0.5440**	7.2010	**7.6298**
Fishing Boat	0.7130	**0.4747**	7.1914	**7.2796**
Male	0.5614	**0.4259**	**7.5237**	7.5131
Moon surface	0.8306	**0.5784**	6.7093	**7.4148**
Stream and bridge	0.6279	**0.3841**	5.7056	**6.9006**
Tank	0.7407	**0.5702**	5.4957	**6.2501**
Tank2	0.8360	**0.6383**	5.9916	**6.9583**
Tank3	0.7367	**0.4749**	6.1898	**6.8043**
Truck and APCs	0.7151	**0.5405**	6.5632	**7.2792**
Truck and APCs2	0.6739	**0.5547**	6.6953	**7.2057**
Truck	0.8096	**0.6486**	6.0274	**6.6620**

enhancement effect. In the following work, we intend to try to change the value of parameters c and α for further research. We also plan to apply FCM-co to other areas, such as image segmentation.

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REFERENCES

[1] R. C. Gonzalez, R. E. Woods, and B.R. Masters, *Digital Image Processing*, 3rd ed, 2009.

[2] R. Hummel, *Image enhancement by histogram transformation*, Computer Graphics and Image Processing. 1977, vol. 6, no. 2, p. 184-195.

[3] S. C. F. Lin, C. Y. Wong, M. A. Rahman, G. Jiang, S. Liu, N. Kwok, H. Shi, Y. H. Yu, T. Wu, *Image enhancement using the 160 averaging histogram equalization (AVHEQ) approach for contrast improvement and brightness preservation*, Computers and 161 Electrical Engineering. 2015, vol. 6, no. 356-370.

[4] G. Ulutas and B. Ustubioglu, *Underwater image enhancement using contrast limited adaptive histogram equalization and layered difference representation*, Multimedia Tools and Applications. 2021, vol. 80, no. 2, 10, p. 15067-15091.

[5] S. Kumar, A. K. Bhandari, A. Raj and K. Swaraj, *Triple clipped histogram-based medical image enhancement using spatial frequency*, IEEE Transactions on NanoBioscience, 2021, vol. 20, no. 3, p. 278-286.

[6] S. C. Huang, F. C. Cheng, and Y. S. Chiu, *Efficient contrast enhancement using adaptive gamma correction with weighting distribution*,IEEE transactions on image processing. 2012, vol. 22, no. 3, p. 1032-1041.

[7] A. Kumar, R. K. Jha and N. K. Nishchal, *An improved Gamma correction model for image dehazing in a multi-exposure fusion framework*, Journal of Visual Communication and Image Representation. 2021, vol. 78, p.103-122.

[8] S. Liu, W. Long, L. He, Y. Li and W. Ding, *Retinex-based fast algorithm for low-light image enhancement*, Entropy. 2021, vol. 23, no. 6, p. 746.

[9] L. S. S. Singh, A. K. Ahlawat, D. K. M. Singh, and T. P Singh, *Image Enhancement Techniques On Fuzzy Domain: A Review*, International Journal of Computer Engineering and Technology. 2017, vol. 8, no. 2, p. 80-99.

[10] H. Deng, C. Duan, X. Zhou, *A novel fuzzy enhancement of mammograms*, 2015 IET International Conference 177 on Biomedical Image and Signal Processing (ICBISP 2015), November 2015, pp. 1-5.

[11] L. Yang, S. Zenian, R. Zakaria, *Fuzzy image enhancement based on algebraic function and cycloid arc length*, 2021 IEEE International Conference on Artificial Intelligence in Engineering and Technology (IICAIET), September 2021, p. 1-4.

[12] H. D. Cheng and H. Xu, *A novel fuzzy logic approach to contrast enhancement*, Pattern recognition. 2000, vol. 33, no. 5, p. 809-19.

[13] M. Hanmandlu, O. P. Verma, N. K. Kumar and M. Kulkarni, *A novel optimal fuzzy system for color image enhancement using bacterial foraging*, IEEE Transactions on Instrumentation and Measurement. 2009, vol. 58, no. 8, p. 2867-2879.

[14] G. Li, Y. Tong and X. Xiao, *Adaptive Fuzzy Enhancement Algorithm of Surface Image based on Local Discrimination via Grey Entropy*, Elsevier Procedia Engineering. 2011, vol. 15, p. 1590 C 1594.

[15] K. Hasikin and N. A. M. Isa, *Enhancement of the low contrast image using fuzzy set theory*, 14th International Conference on Modelling and Simulation, March 2012, p. 371-376.

[16] A. K. Gupta, S. S. Chauhan and M. Shrivastava, *Low contrast image enhancement technique by using fuzzy method*, International Journal of Engineering Research and General Science. 2016, vol. 4, no. 2, p. 518-526.

[17] V. Magudeeswaran and J. F. Singh, *Contrast limited fuzzy adaptive histogram equalization for enhancement of brain images*, International Journal of Imaging Systems and Technology. 2017, vol. 27, no. 1, p. 98-103.

[18] S. Zenian, T. Ahmad, and A. Idris, *Intuitionistic fuzzy set: FEEG image representation*, AIP Conference Proceedings 2184,060054(2019), 2019.

[19] S. Zenian, T. Ahmad, and A. Idris, *Fuzzy contrast enhancement by intensification operator in Flat Electroencephalography Image*, Transactions on Science and Technology. 2019, vol. 6, no. 2-2, p. 216-220.

[20] J. C. Dunn, *A fuzzy relative of the ISODATA process and its use in detecting compact well-separated clusters*, Journal of Cybernetics. 1973, vol. 3, p. 32-57.

[21] J. C. Bezdek, *Objective function clustering*, Pattern recognition with fuzzy objective function algorithms, Springer, 1981, p. 43-93.

[22] D. Naik and P. Shah, *A review on image segmentation clustering algorithms*, Int J Comput Sci Inform Technol. 2014, vol. 5, no. 3, p. 3289-93.

[23] L. Chen, Z. Li, Z. Li, S. Chen, Q. Yang and Y. Du, *A Contrast Enhancement Method of Infrared Finger Vein Image Based on Fuzzy Technique*, 2019 IEEE 14th International Conference on Intelligent Systems and Knowledge Engineering (ISKE), November 2019, p. 307-310.

[24] T. Chaira and A. K. Ray, *Fuzzy image processing and applications with MATLAB*, CRC Press, 2017.

[25] R. Kumar and A. K. Bhandari, *Fuzzified Contrast Enhancement for Nearly Invisible Images*, IEEE Transactions on Circuits and Systems for Video Technology. 2021, vol. 32, no. 5, p. 2802-2813.

[26] M. Hanmandlu, D. Jha and R. Sharma, *Color image enhancement by fuzzy intensification*, Pattern recognition letters. 2003, vol. 24 no. 1-3, p. 81-87.

[27] R. C. Gonzalez, R.E. Woods and S.L. Eddins, *Digital Image Processing Using MATLAB*, New Jersey, Prentice Hall, 2003.

[28] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, *Image quality assessment: from error visibility to structural similarity*, IEEE transactions on image processing. 2004, vol. 13 no. 4, p. 600-612.