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

Libao Yang  
Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Kota Kinabalu, 88400

Suzelawati Zenian*  
Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Kota Kinabalu, 88400

Rozaimi Zakaria  
Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Kota Kinabalu, 88400

Abstract—Image enhancement is an important method in the process of image processing. This paper proposes an image enhancement method based 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 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:
Image $I = \{x_{k,p} | k = 1, 2, 3, \ldots, m, p = 1, 2, 3, \ldots, n\}$, where $x_{k,p}$ is the gray scale of the pixel in row $k$ and column $p$ of the image. $I^* = \{x_{k,p}^*, x_{k,p} = \text{mean}(x_{k,p}) \text{ and around } x_{k,p}\}$ is the cooperation matrix of Image $I$. In the Eq. (1), $X = \{x_{i,j} | x_{i,j} = x_{k,p}, j = (k-1)n + p, 1 \leq k \leq m, 1 \leq p \leq n, x_{k,p} \in I\}$, similarly, $X^* = \{x_{i,j}^*, x_{i,j} = x_{k,p}^*, j = (k-1)n + p, 1 \leq k \leq m, 1 \leq p \leq n, x_{k,p}^* \in I^*\}$, $N = mn$, $c$ is the number of clusters. $u_{ij}$ is the degree of membership of $x_{ij}$ and $x_{ij}^*$ 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 $i$, $\|x_{ij} - v_i\|^2$ is a distance measure between object $x_{ij}$ and cluster center $v_i$, $\|x_{ij}^* - v_i^*\|^2$ is a distance measure between object $x_{ij}^*$ and cluster center $v_i^*$. The parameter $\alpha$ is a constant. By definition, each point $x_{ij}$ satisfies the constraint that $\sum_i u_{ij} = 1$. The object function $J_m$ can be obtained by iterating as follows:

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

Step B: Calculate the $v_i$ and $v_i^*$ by

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

and

$$v_i^* = \frac{\sum_{j=1}^{N} u_{ij}^m x_{ij}^*}{\sum_{j=1}^{N} u_{ij}^m}. \quad (3)$$

Step C: Update $u_{ij}$

$$u_{ij} = \frac{\sum_{k=1}^{c} \left( \|x_{ij} - v_k\|^2 + \alpha \|x_{ij}^* - v_k^*\|^2 \right) - \frac{1}{\alpha} \|x_{ij} - v_i\|^2}{\sum_{k=1}^{c} \|x_{ij} - v_k\|^2 + \alpha \|x_{ij}^* - v_k^*\|^2}. \quad (4)$$

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

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

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:

$$u_{ij}^*(x_{ij}) = \begin{cases} u_{ij}(x_{ij}), & x_{ij} \leq \hat{v}_i = 1, 2, \ldots, c \\ 1 + \frac{1 - u_{ij}(x_{ij})}{2}, & x_{ij} > \hat{v}_i = 1, 2, \ldots, c \end{cases}. \quad (6)$$

In the Eq.(6), $j = 1, 2, 3, \ldots, N$. $u_{ij}^*(x_{ij})$ 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:

$$y_j = \frac{1}{c} \sum_{i=1}^{c} u_{ij}^*(x_{ij}) x_{ij}, \quad j = 1, 2, \ldots, N. \quad (7)$$

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: $m, c, \alpha$, and $\epsilon$.

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.
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-to-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.

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

\[
PSNR = 10 \times \log_{10} \left( \frac{2^n - 1}{MSE} \right) dB. \tag{9}
\]
In Eq. (9), \( n = 8 \) (the test image is 8bit image). In equation (10), \( \mu_x \) is the mean of \( x \), \( \mu_y \) is the mean of \( y \), \( \sigma_x^2 \) is the variance of \( x \), \( \sigma_y^2 \) is the variance of \( y \), \( \sigma_{xy} \) 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/dataset.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.

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

| Image          | Original | Proposed | Original | Proposed |
|----------------|----------|----------|----------|----------|
| APC            | 0.7640   | 0.6601   | 5.0374   | 5.5669   |
| Aerial         | 0.6868   | 0.4045   | 7.3118   | 6.8089   |
| Aerial2        | 0.5362   | 0.2484   | 6.9940   | 6.0122   |
| Airplane       | 0.3171   | 0.1507   | 5.6415   | 4.8032   |
| Airplane2      | 0.5756   | 0.2566   | 4.0045   | 4.3660   |
| Airport        | 0.6210   | 0.4144   | 6.8303   | 6.7248   |
| Car and APCs   | 0.7875   | 0.6152   | 6.1074   | 6.8027   |
| Car and APCs2  | 0.7743   | 0.6124   | 5.9085   | 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   | 7.2101   | 7.6298   |
| Fishing Boat   | 0.7130   | 0.4747   | 7.1914   | 7.2296   |
| 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   | 5.4977   | 6.2901   |
| Tank2          | 0.8360   | 0.6383   | 5.9916   | 6.9283   |
| Tank3          | 0.7567   | 0.4749   | 6.1898   | 6.8043   |
| Truck and APCs | 0.7151   | 0.4092   | 6.5612   | 7.2792   |
| Truck and APCs2| 0.6139   | 0.3547   | 6.0953   | 7.2057   |
| Truck          | 0.8096   | 0.6486   | 6.0974   | 6.6620   |

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

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