Gray World Based Fuzzy C-Means Satellite Image Segmentation

Nitin Sharma, Rajni Sharma, and Kanchan Sharma

Abstract Satellite image segmentation is used to partition an image into subregions and recognize the multiple objects of the same class as a single entity. This paper proposes a novel gray world based Fuzzy C-Means (GBFCM) a clustering-based satellite image segmentation technique. To achieve the objective of an increase in the spatial information, contrast, local detail present in the satellite image and to reduce the computation time, the gamma correction method is introduced in the proposed approach. The most basic attribute of the image cluster is its reduction of intensity from a cluster centre which improves by modification of gamma values. To measure the effectiveness of the proposed cluster-based segmentation approach, Signal-to-Noise Ratio (SNR), Mean Square Error (MSE), Mean Absolute Error (MAE), Peak Signal-to-Noise Ratio (PSNR) is considered and compared with the recent schemes. The results confirm that the proposed approach efficiently enhanced the resolution of the satellite image in comparison to the state-of-the-art resolution algorithms namely OTSU, Thresholding, K-means, and is found to outperform in all the methods.

Keywords Gray world · Fuzzy C-means · K-means · Segmentation · Resolution · Satellite images

1 Introduction

Satellite images consist of multispectral information and are being used in number of areas like climate-related studies, agriculture, landscape, geology, fishery, etc. [1].

N. Sharma (✉)
Department of ECE, Maharaja Agrasen Institute of Technology (GGSIPU), Delhi, India
e-mail: nitinsharma@mait.ac.in

R. Sharma
School of Computing, Galgotia University, Greater Noida, India
e-mail: rajnisharma.hp@gmail.com

K. Sharma
Department of ECE, Indira Gandhi Delhi Technical University for Women, Delhi, India
e-mail: sharma_kanchan@yahoo.com

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Satellite image enhancement is of profound interest in the current scenario due to which researchers are continuously working to improve the quality of the captured image. These images are captured from high altitude in space which usually involves conditions beyond human control. Moreover, these images are poorly illuminated and have a very low spatial resolution. Due to this, too many objects (or regions) remain unrecognized. These regions, therefore, are required to be enhanced in such a way that it retains the spatial information and the appropriate greyness. To provide a definite class in the desired region with certainty for a satellite image is always a typical task. This task is achieved by using Fuzzy based method that handles the problem by associating certainty factors with class labels.

Generally, the homogeneous region present in the satellite images contains valuable information required to detect the texture and pattern of different shades present in the low-resolution satellite images. These objects are determined on the basis of gray shades by using the clustering approach [2–4]. The main challenge behind the satellite images is to extract the actual information present in the captured image by the camera. Therefore, the clustering approach is able to distinguish various regions captured in the low-resolution satellite image used for further analysis. The clustering approach segments the image according to the pixel gray value similarity. The main goal of using satellite image segmentation is to classify pixels into homogeneous regions based on specific characteristics of the image. The homogeneous groups are performed in two ways, either by a supervised approach to learning or by unsupervised approach to learning. Supervised learning approach considers the standard data set which is used to train the system and thereafter the learned system is tested, hence the clustering using this method is referred to as supervised clustering [5, 6]. In the other method, data set is not used to train the system, hence this clustering approach is called unsupervised clustering [7, 8]. The unsupervised clustering is more popular than supervised clustering. The algorithms like k-mean, Fuzzy C-Means (FCM) are examples of an unsupervised algorithm [9, 10]. K-means clustering procedure has a simple and easy way to classify a given dataset into a number of apriori-fixed clusters (assuming k clusters). FCM clustering allows two or more clusters to belong to one piece of data [11]. The FCM-based clustering method; a popular choice for segmentation has been investigated in the works of [12, 13]. The purpose of segmentation in the proposed approach is to enhance the low-resolution image by using a spatial domain technique [15–19].

The proposed approach GBFCM is different from the existing clustering segmentation algorithms. GBFCM makes cluster formation so that pixels belonging to the same cluster are more correlated than pixels belonging to other clusters. The proposed technique involves the gamma correction method which enables fast computation and gets better detail in the satellite image. The paper is organized as follows. In Sect. 2, we present the basic concepts of the clustering approach for image analysis. The general context that justifies the FCM method and modifies the FCM-based approach in satellite image segmentation is explained in Sect. 3. The performance metric used is discussed in Sect. 4. Simulation results obtained in reference to the application of proposed GBFCM to satellite images are given in Sect. 5. Finally, Sect. 6 concludes the paper.

2 K-Means Clustering

Data vectors are placed in a fixed number of clusters in K-Means algorithms. Initially, the fixed cluster centroids are randomly allocated. The centroid size is the same as the data vector size or length. The cluster assignment to each pixel is carried out on the basis of nearness or closeness given by the computation of Euclidean distance measurement. When all the pixels are mapped or get assigned cluster, the re-computation of the mean of each cluster is carried out. This process is repeated until no significant changes are observed for each cluster mean or for some fixed number of iterations [7].

This clustering technique was identified as one of the most efficient image segmentation methods. A number of hybrid algorithms using K-means with other optimization techniques have been presented in the literature which improves the segmentation of the image to a much-optimized scale.

Algorithm 1 K-Means Algorithm

1. Randomly initialize the K cluster centres.
2. Compute the Euclidean distance for each pixel and pixel map to a cluster with the minimum distance to its cluster centre.
3. Obtain the mean pixel values in each cluster and formed new cluster centres.
4. Repeat the above two steps until the convergence occurs.

3 Proposed Gray-Scale-Based Fuzzy C-Means (GBFCM)

FCM algorithm usually improves the ruggedness of regions. This is also due to the conformity of the clustering and less complexity of the method; its applications in different areas of image analysis. Therefore, the pixels are clustered to display the pixels of the same cluster as a region [11].

To develop a new FCM-based algorithm with less computational cost, a gamma correction based method is introduced. Its basic criterion is required to minimize the objective function given by,

$$J_m = \sum_{i=1}^{N} \sum_{j=1}^{C} u_{ij}^{m} |x_i^{\gamma} - c_j|^2 \tag{1}$$

where m is any real number greater than 1. u_{ij} is the membership degree of x_i in the cluster j. x_i is the i^{th} d—dimensional measured data, γ is the power operator (or gamma) values lies between 0 and 1, c_j is the d—dimension centre of the cluster.

The proposed GBFCM method is described in the flowchart shown in Fig. 1. First, we initialize the cluster centres and read the input image as gray values. Thereafter

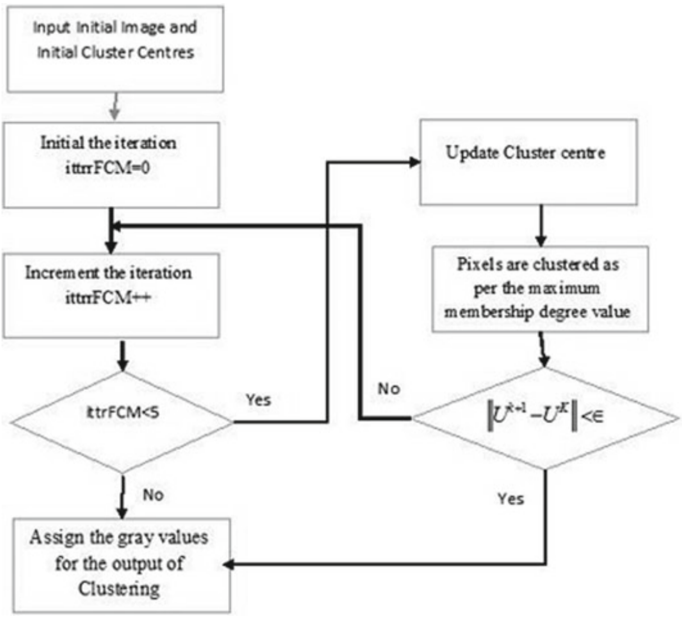

Fig. 1 Flowchart of proposed GBFCM method

the obtained gray values are clustered into five different clusters in five number of iterations based on the degree of membership function values that minimizes the given objective function at the optimal value of gamma (γ) as given in Eq. 1.

These five regions carried significant information in under or overexposure conditions. The pixels having exposure in terms of gray shades shows the hierarchal position of objects present, in the satellite image. The proposed GBFCM-based method shows pixels in terms of different grayscale values.

Algorithm 2 FCM Algorithm

1. Initialize matrix $U = [u^{ij}]$ randomly, i.e. say $U(0)$
2. In kth step: compute the centres vectors $c(k) = [c_j]$ with $U(k)$

$$c_j = \frac{\sum_{i=1}^{N} u_{ij}^{m} * x_i^{\gamma}}{\sum_{i=1}^{N} u_{ij}^{m}} \tag{2}$$

3. After computation of centre vectors, update the value of U_k and U_{k+1}

$$U_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\left\| \frac{x_i^{\gamma} - c_j}{x_i^{\gamma} - c_k} \right\| \right)^{\frac{2}{m-1}}} \tag{3}$$

4. Check whether $\left\| U^{k+1} - U^{k} \right\| < \in$ If it is True then
5. STOP; otherwise continue and return to step 2.

Therefore, the different hierarchal regions are easily detectable. It also detects the changes observed with time by using the same captured image.

By introducing gamma correction to an objective function shows better performance for image segmentation of satellite images. These five centres increase or decrease the intensity values according to the gamma value. Finally, we assign the fixed five different gray values to each cluster obtained. These clusters segment the image as per the pixel similarity. These five homogenous regions detect the information in different shades. The proposed method modifies objective function by using the gamma values instead of the slower distance computation that reduces the pixels within local spatial neighbours and their clustering centres, which leads to low computational complexity. Therefore, in this paper, we introduce GBFCM-based method used in segmentation and address the problems associated with conventional thresholding based methods. Here, gamma correction reduces the shadowing effect that is favourable to satellite image segmentation.

4 Performance Metric

The four quantitative parameters are used in performance evaluation of the proposed technique and compared with the available existing technique are as follows.

4.1 Measurement of Signal-to-Noise Ratio (SNR)

The Signal-to-Noise ratio (SNR) is one of the most important statistical parameters for image or signal quality measurement. It is the ratio of signal power to noise power. It is mathematically represented as

$$\text{SNR (in dB)} = 10\log_{10}\left[\frac{P_{\text{signal}}}{P_{\text{noise}}}\right] \tag{4}$$

where P_{signal} is the mean or expected value of the signal and P_{noise} is the variance of noise. When a value of SNR ratio higher than 1 (0 dB) then the power of the signal is higher in comparison to the power of the noise, this ensures lower distortion and less noise-induced interference.

4.2 Measurement of Mean Square Error (MSE)

Mean Square Error (MSE) is characterized as the error square expectation. This error is perhaps the difference between quantity of desire $f(i, j)$ and quantity estimated $F(i, j)$ for each pixel of the image [14].

$$\text{MSE} = \sum_{i=1}^{M} \sum_{j=1}^{N} |f(i, j) - F(i, j)|^2 / M \times N \tag{5}$$

The MSE is a way of selecting the best estimator. Ideal value of Mean Square Error is equal to zero.

4.3 Measurement of Peak Signal-to-Noise Ratio (PSNR)

Peak Signal-to-Noise Ratio (PSNR) is expressed as a ratio of the maximum signal power value to the noise power value that affects its representation's fidelity. Generally, it was in decibel (dB) terms. It is widely used in compression algorithms as a statistical measure of image reconstruction overall quality [15]. It is expressed mathematically by using the mean squared error (MSE) which is defined as a noisy approximation of another for two different $M \times N$ monochrome images are given by:

$$\text{PSNR} = 10 \log_{10}\left(\frac{\text{MAX}^2}{\text{MSE}}\right) \tag{6}$$

Here, MAX is the maximum pixel intensity value which is equal to 255 for an 8-bit image.

4.4 Measurement of Mean Absolute Error (MAE)

Mean Absolute Error (MAE) is the absolute difference between the reference image and test image [15]. It is given as

$$\text{MAE} = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} \left|\hat{X}(i, j) - X(i, j)\right|}{M \times N} \tag{7}$$

5 Simulation Results and Discussions

This section discusses the tools used for the simulation. It also describes the result obtained by the different classical and proposed method of image segmentation in detail.

5.1 *Methodology Used*

By using MATLAB 7.1 on Intel 64 bit processor I3, the proposed method was successfully simulated. Around 120 images have been tested and some of them (three) are presented here. We consider the discussed four performance metrics Mean Squared Error (MSE), Signal-to-Noise Ratio (SNR), Peak Signal-to-Noise Ratio (PSNR) and Mean Absolute Error (MAE). These metrics are evaluated for three different satellite images and tabulated in Table 1. It clearly shows from the result obtained that the proposed GBFCM method is better among the other methods. Figures 2a, 3a and 4a show the Low contrast satellite image from NASA's Earth Observatory. Figures 2b, 3b and 4b show the resulting image obtained by applying Otsu's method on the low contrast satellite image. Figures 2c, 3c and 4c show the K-mean clustering-based satellite images. Figures 2d, 3d and 4d show the resulted Fuzzy C-means based enhanced and segmented satellite images.

Figures 2d, 3d and 4d depict a much better performance in comparison to Otsu's and other threshold methods conventionally used for image segmentation. These images show more detail as compared to the other methods. Figure 2d shows that the brightness is more in the high-intensity region as compared to the other methods.

Table 1 Performance metrics—SNR, PSNR, MSE AND MAE values for GBFCM, OTSU, thresholding, and K-means clustering methods

	Methods	SNR	PSNR	MSE	MAE
Figure 2	Proposed method	56.69	15.0755	2020.78	35.10
	OTSU method	48.20	6.58508	14,274.85	110.43
	Thresholding	48.23	6.61214	14,186.18	109.92
	K-means clustering	48.37	6.75625	13,723.198	108.17
Figure 3	Proposed method	52.44	14.3043	2413.50	38.71
	OTSU method	48.22	10.0812	6382.04	68.35
	Thresholding	48.24	10.1002	6354.13	68.12
	K-means clustering	48.44	10.3036	6063.40	66.35
Figure 4	Proposed method	55.61	6.58793	14,265.50	91.517
	OTSU method	52.47	3.44290	29,429.94	142.92
	Thresholding	52.47	3.447052	29,401.88	142.82
	K-means clustering	52.55	3.5223	28,896.72	141.15

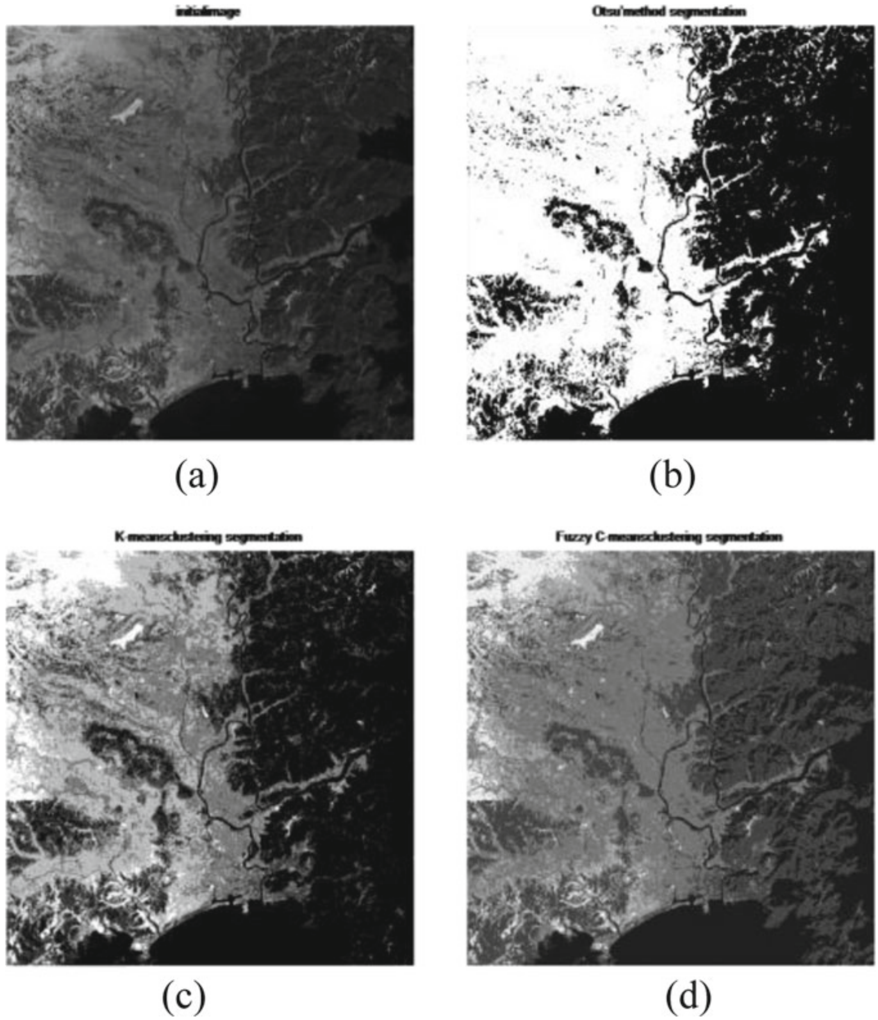

Fig. 2 **a** Low contrast satellite image from NASA's Earth Observatory. **b** OTSU method based satellite image. **c** K-means clustering-based satellite image. **d** Proposed GBFCM-based enhanced satellite image

In other methods, the intensity value gets increased in the low-intensity region. The signal-to-noise ratio achieved is 56.69 dB which is comparable with the threshold method, Otsu's, k-mean clustering as 48.20 dB, 48.23 dB, 48.37 dB, respectively. When we applied the same proposed method on the other two test images it showed that the resulting image obtained is more likely suitable than the other three techniques. Figures 3d and 4d show more information in terms of gray shades. Table 1 depicts that the signal-to-noise ratio has values 52.44 dB, 55.61 dB which is higher than the other techniques. Similarly, we have shown for other two test images that

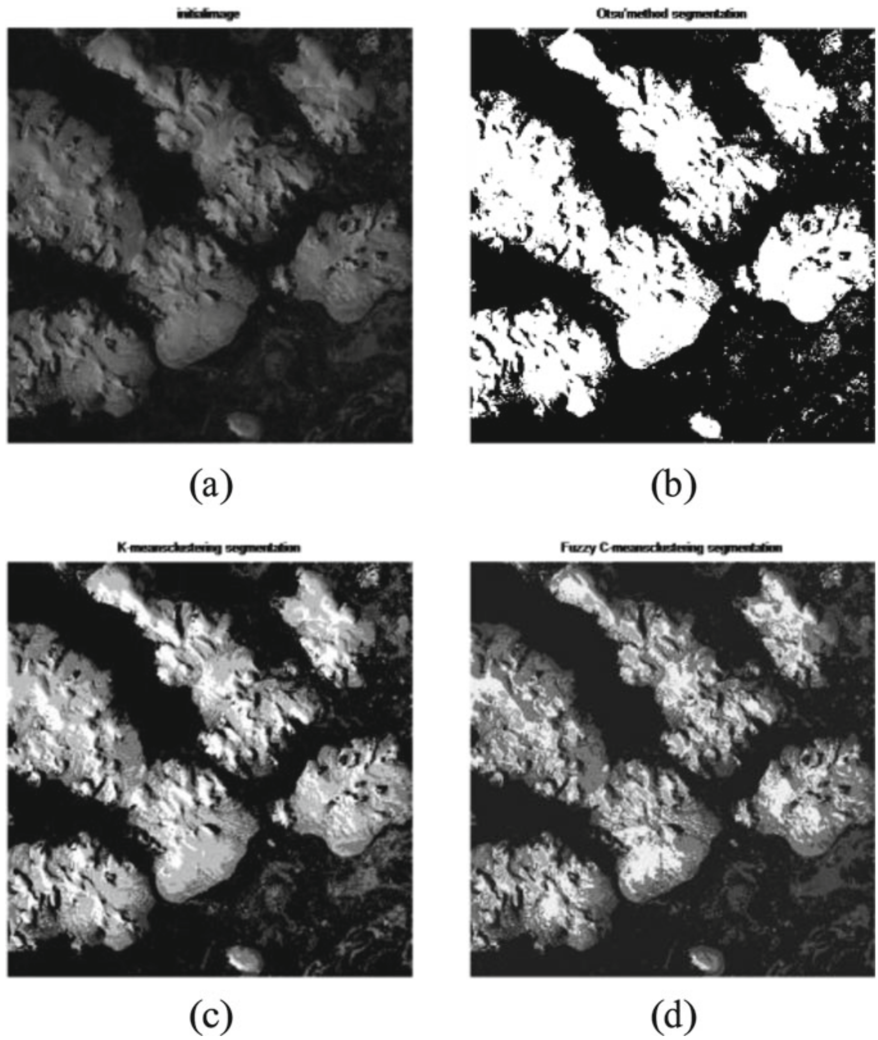

Fig. 3 **a** Low contrast satellite image from NASA's Earth Observatory. **b** OTSU method based satellite image. **c** K-means clustering-based satellite image. **d** Proposed GBFCM-based enhanced satellite image

the proposed method performs well as compared to the other three techniques. In Fig. 4d, we have shown that the image obtained from the proposed method is brighter than the other methods even though it has more details and brighter than the other. The proposed method shows that the contrast and intensity increases by maintaining the original information in the image but other methods fail to maintain the original information as seen in the test images.

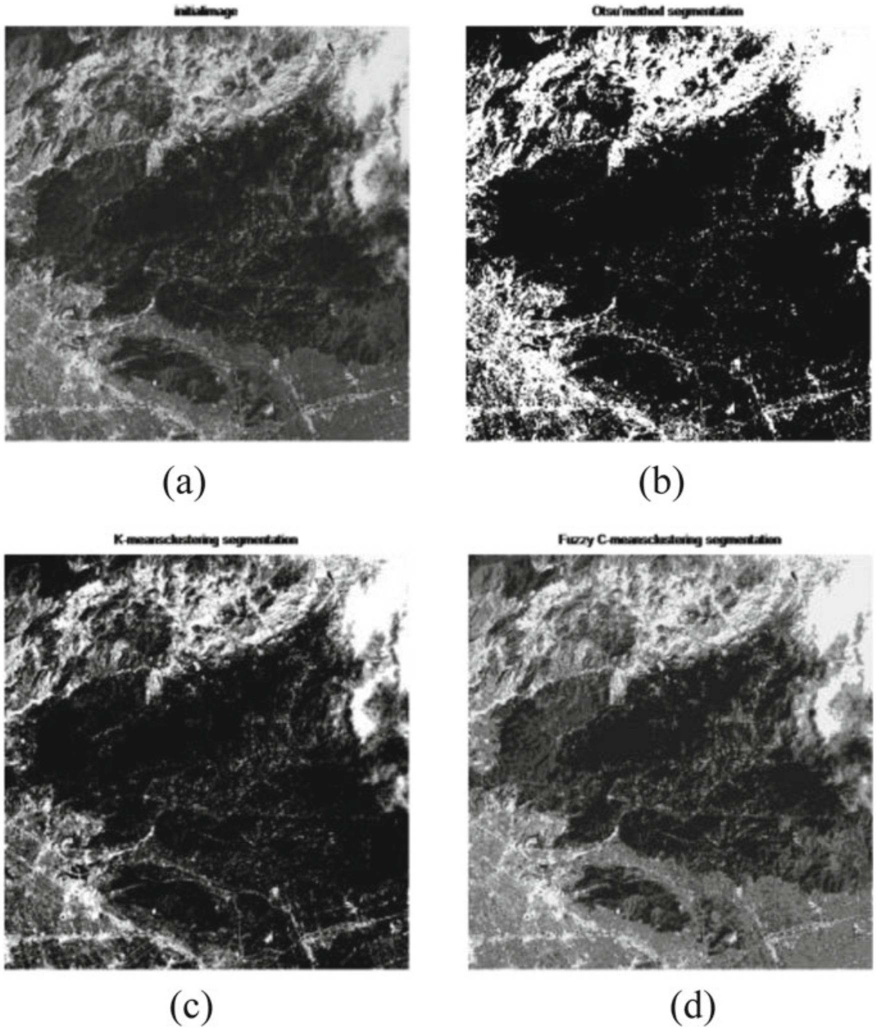

Fig. 4 **a** Low contrast satellite image from NASA's Earth Observatory. **b** OTSU method based satellite image. **c** K-means clustering-based satellite image. **d** Proposed GBFCM-based enhanced satellite image

6 Conclusions

There are many fuzzy clustering algorithms, but the algorithm used most often in satellite image segmentation is the FCM algorithm because of the fact that ambiguity can be handled and much more information can be given compared to K-means. Also for noise-free images, the FCM algorithm works well. This work is also useful for the classification of the images. The proposed GBFCM uses gamma correction which is faster in distance computation and more detailed information can be achieved.

The proposed algorithm confirms its statistical approaches effectiveness by comparing the results attained with the existing SNR approach and gaining higher values for PSNR, whereas, MSE and MAE are lower, which signifies that the image achieves more fine details as compared to the other methods. It can, therefore, be proved that the performance of the proposed algorithm is much better than that of the existing approach.

References

1. Gonzalez RC, Woods RE (2002) Digital image processing, 2nd edn. Prentice Hall
2. Reddi SS, Rudin SF, Keshavan HR (1984) An optimal multiple threshold scheme for image segmentation. IEEE Trans Syst Man Cybern 4:661–665
3. Boukharouba S, Rebordao JM, Wendel PL (1985) An amplitude segmentation method based on the distribution function of an image. Comput Vis Graph Image Process 29:47–59
4. Nakib A, Oulhadj H, Siarry P (2009) A thresholding method based on two-dimensional fractional differentiation. Image Vis Comput 27(9):1343–1357
5. Wang F (1990) Fuzzy supervised classification of remote sensing images. IEEE Trans Geosci Remote Sens 28(2):194–201
6. Vannier MW et al (1985) Multispectral analysis of magnetic resonance images. Radiology 154(1):221–224
7. Celik Turgay (2009) Unsupervised change detection in satellite images using principal component analysis and k-means clustering. Geosci Remote Sens Lett IEEE 6(4):772–776
8. Sohn Y, Sanjay Rebello N (2002) Supervised and unsupervised spectral angle classifiers. Photogram Eng Remote Sens 68(12):1271–1282
9. Mitra P, Uma Shankar B, Pal SK (2004) Segmentation of multispectral remote sensing images using active support vector machines. Pattern Recogn Lett 25(9):1067–1074
10. Jianzhuang L, Wenqing L, Yupeng T (1991) Automatic thresholding of gray-level pictures using two-dimension Otsu method. In: 1991 International conference on circuits and systems, 1991. Conference proceedings, China. IEEE, pp 325–327
11. Bezdek JC, Ehrlich R, Full W (1984) FCM: The fuzzy c-means clustering algorithm. Comput Geosci 10(2):191–203
12. Bandyopadhyay S (2005) Satellite image classification using genetically guided fuzzy clustering with spatial information. Int J Remote Sens 26(3):579–593
13. Dulyakarn P, Rangsanseri Y (2001) Fuzzy c-means clustering using spatial information with application to remote sensing. In: 22nd Asian conference on remote sensing. vol 5
14. Hore A, Ziou D (2010) Image quality metrics: PSNR versus SSIM. In: 20th International conference on pattern recognition (ICPR). IEEE, pp 2366–2369
15. Sharma N, Verma OP (2014) Gamma correction based satellite image enhancement using singular value decomposition and discrete wavelet transform. In: 2014 IEEE international conference on advanced communications, control and computing technologies. IEEE, pp 1286–1289
16. Sharma N, Verma OP (2017) A novel fuzzy based satellite image enhancement. In: Proceedings of international conference on computer vision and image processing. Springer, Singapore, pp 421–428
17. Pal SK, Ghosh A, Shankar BU (2000) Segmentation of remotely sensed images with fuzzy thresholding, and quantitative evaluation. Int J Remote Sens 21(11):2269–2300

18. Sharma N, Verma OP (2017) Estimation of weighting distribution using fuzzy memberships and wavelet transformation with PSO optimization in satellite image enhancement. Cogent Eng 4(1):1–13. https://doi.org/10.1080/23311916.2017.1392835
19. Lv Z, Liu T, Shi C, Benediktsson JA, Du H (2019) Novel land cover change detection method based on k-means clustering and adaptive majority voting using bitemporal remote sensing images. IEEE Access 7:34425–34437