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Color image segmentation using adaptive unsupervised clustering approach

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ABSTRACT

This paper presents the Region Splitting and Merging-Fuzzy C-means Hybrid Algorithm (RFHA), an adaptive unsupervised clustering approach for color image segmentation, which is important in image analysis and in understanding pattern recognition and computer vision field. Histogram thresholding technique is applied in the formation of all possible cells, used to split the image into multiple homogeneous regions. The merging technique is applied to merge perceptually close homogeneous regions and obtain better initialization for the Fuzzy C-means clustering approach. Experimental results have demonstrated that the proposed scheme could obtain promising segmentation results, with 12% average improvement in clustering quality and 63% reduction in classification error compared with other existing segmentation approaches.

1. Introduction

Data clustering divides objects into clusters, such that similar objects are grouped together in the same cluster [1]. In scientific literature, the clustering technique is commonly used to segment regions of interest [2–4] and detect the borders of objects in an image [5–8]. Thus, clustering techniques for image segmentation and edge detection have been used in various applications, including object recognition [9–12], optical character recognition [13,14], face recognition [15–17], fingerprint recognition [18,19] and medical image processing [20,21].

Fuzzy C-means (FCM) clustering is one of the most popular techniques for image segmentation [22]. This technique introduces the fuzzy concept so that an object can belong to more than one class simultaneously. Membership degree is the strength of the association between an object and a class, with a value in a normalized fashion. As an unsupervised technique, FCM clustering does not require prior knowledge about the tested data. However, this technique has difficulties obtaining proper initial cluster centers and a sufficient number of clusters for initialization [23]. The initialization for the FCM clustering technique plays a vital role in obtaining optimum final cluster centers. Without proper initialization, this technique could generate sets of poor final cluster centers that could wrongly represent the clusters.

Some initialization methods have been proposed for FCM clustering. Random initialization was proven to be the best initialization method for the C-means family because it produces good final cluster centers [24]. However, random initialization does not have an adaptive decision mechanism for cluster numbers. Similar observation could be found in one of the latest works reported by Ji et al. [25], i.e. the weighted image patch-based FCM (WIPFCM) algorithm. In the WIPFCM algorithm, image patch, instead of image pixel, is employed as the basic unit to be clustered. A weighting scheme is proposed to adaptively determine the anisotropic weight of each pixel in the patch, as not all of them contribute equally to calculate the similarity between two patches [25]. Despite of its ability in producing good segmentation results and its robustness toward the noise, the prior determination of cluster numbers in the WIPFCM algorithm is set manually by user. The main drawback of this strategy is, it generally requires a laborious process of selecting the number of clusters. Additionally, it is impractical to expect all users to have sufficient domain knowledges in determining the correct cluster numbers. Wrong determination of cluster numbers by the user could affect the segmentation results considerably as the initialization scheme has substantial impact on the FCM's clustering performance.

To mitigate the abovementioned drawbacks, the improved Ant System (AS) was introduced [26] to automatically obtain initial cluster centers and the number of clusters for the FCM clustering technique. The concept of the Ant Colony algorithm (ACA), with its intelligent searching ability, is applied in AS to obtain better optimization of clustering results. AS could provide effective initialization for the FCM clustering technique because of its adaptive decision mechanism for cluster numbers. Agglomerated Just Noticeable Difference Histogram (AJNDH) [27] is another adaptive cluster initization scheme that counters the drawback of the random initialization scheme. Different from the AS initialization

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scheme that employs the intelligence searching ability to optimize the initial cluster, the AJNDH initialization scheme adopts the concept of histogram bins in determining the initial cluster. The histogram bins of the color images are calculated in such a way that each color bin in the histogram represents a visually different color. As a result, the number of colors present in the histogram bins is significantly less than the number of unique colors in the color image. The number of histogram bins can be further reduced using the agglomeration technique by introducing an agglomeration threshold to combine the perceptually similar color segments into a larger color segment. The drastic reduction in the number of unique colors in the color images suggest the feasibility of the AJNDH technique in real-time machine analysis applications.

Chen et al. [28] proposed a FCM-based segmentation technique by the fusion on multi-color space components. In their approach, the input images are firstly converted into six color spaces, i.e. grayscale, HSV, YIQ, YCbCr, LAB and LUV color spaces, and the color space components of gray, V, I, Cr, B, and U from the corresponding color spaces are then selected. A peak-finding algorithm is applied on these components to determine their corresponding initial cluster centers and the number of clusters. The spatial FCM (SFCM) algorithm [29] is then used to generate six different initial segmentation results from these six selected components with different cluster numbers. To calculate the final cluster numbers, the SFCM algorithm is applied again to fuse the previous six segmentation results. Bahght et al. [30] proposed a new validity index to access the validity of a cluster. In their approach, a multi-degree entropy algorithm is proposed to perform partition on the input image into different level of intensities using the multi-degree immersion process. Merging technique is then applied on the aforementioned process's output to obtain the final cluster numbers based on the predefined validity function criteria. Meanwhile, Sowmya and Sheela Rani [31] investigated the capability of FCM, possibilistic FCM (PFCM) [32], and competitive neural network (CNN) [33] in performing the image segmentation. In their investigation, a self-estimation algorithm proposed in [34] are adopted to automatically determine the cluster numbers.

In this paper, we propose the Region Splitting and Merging-Fuzzy C-means Hybrid Algorithm (RFHA) that consists of two main modules: Region Splitting and Merging (RSM) and FCM clustering. A color image with RGB representation is composed of multiple homogeneous regions having different intensity ranges for each color channel. The pixels belong to each homogeneous region, with intensity values within the intensity ranges of that homogeneous region for each color channel. In the RSM module, the histogram thresholding technique can successfully detect the valleys in the histogram of each color channel and can be applied in the formation of all possible cells, which are used to split the image into multiple homogeneous regions. The endpoints of these cells can be obtained by taking the adjacent valleys in the histogram of each color channel to form the intensity ranges of the homogeneous regions for each color channel and thus produce multiple homogeneous regions. The merging technique is applied to merge perceptually close homogeneous regions and obtain better initialization for the FCM clustering technique. Finally, the initial cluster centers and the number of clusters are obtained and used as initialization for the FCM clustering technique.

The rest of the paper is organized as follows. Section 2 presents in detail the RSM and FCM clustering modules of the proposed approach and provide illustrations of the implementation procedure of the RFHA technique. Section 3 analyzes the experimental results obtained from the RFHA and compares them with existing segmentation approaches. Section 4 concludes the results of this paper.

2. Proposed approach

The iterative optimization of the FCM clustering technique is essentially a local searching method that has a tendency to fall onto local minimum points. However, the FCM clustering technique is very sensitive to the initialization condition of the initial cluster centers and the number of clusters [23]. Thus, the image segmentation results produced by the FCM clustering technique depend on the initialization condition. Usually, good initialization conditions can only be obtained by running repetitive experiments based on certain experiences. As a result, a laborious process is generally required to obtain good initialization conditions for the FCM clustering technique [23].

In this paper, an adaptive unsupervised clustering that utilizes the RSM module as the initialization scheme for the FCM clustering technique is proposed. The proposed method RFHA aims to improve the conventional FCM clustering technique by eliminating the limitations of the conventional FCM clustering technique. A block diagram of the proposed RFHA technique is shown in Fig. 1 to provide a general idea of the proposed RFHA technique in a more comprehensive manner. As shown in Fig. 1, the proposed RFHA technique consists of two modules: RSM and FCM clustering. These two modules are presented in detail in Sections 2.1 and 2.2 respectively.

This study uses the RSM module as an initialization scheme that allows users to determine cluster numbers and centroids automatically and adaptively. The obtained cluster numbers and centroids serve as the initialization conditions for the FCM clustering module. Compared with the widely used random initialization scheme, the initialization scheme based on the RSM module requires a less laborious process and consistently produces good initialization conditions for the FCM clustering module. The capability of the RSM module to determine cluster numbers and centroids automatically and adaptively is due to the capacity of the RSM module to detect them based on the global information in the histogram of the input images. Different types of input images have different types of global information. Therefore, the RSM module eventually detects different cluster numbers and centroids depending on the numbers and intensity values of the significant peaks that are present in the histograms of the input images.

More specifically, each pixel in a color image with RGB representation consists of a mixture of intensity of the red, green, and blue color channels. Hence, the histogram of the red, green, and blue color channels could produce global information on the entire image. The basic analysis approach to a histogram is that a homogeneous region tends to form a significant peak in the histogram and that the valley between the adjacent significant peaks could be used as the threshold between these homogeneous regions. Thus, the histogram thresholding is used as a popular segmentation technique that searches for peaks and valleys in the histogram for gray-scale images [35,36]. However, the typical segmentation approach based on the histogram analysis could work well only if the significant peaks in the histogram can be recognized correctly.

For a color image, the pixels belonging to a homogeneous region must have a certain range of intensity for each color channel. For each homogeneous region, the pixels belonging to that homogeneous region have the intensity values within the intensity ranges of that homogeneous region for each color channel. In the RSM module, we apply the histogram thresholding technique to determine the significant peaks in the histogram of each color channel and then obtain the valleys between adjacent significant peaks in the histogram of each color channel. The valleys in the histogram of each color channel are used to form the endpoints of each color channel of the cells, which correspond to the intensity ranges of each color channel of the homogeneous regions. As a result, all possible cells with different volumes are formed. These cells are used