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Research on Clustering Methods for Color Image Segmentation

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Abstract: The research of image segmentation mainly includes: how to select the appropriate color space, reduce the complexity of segmentation algorithm, improve the noise resistance and universality of segmentation algorithm, etc. Fuzzy clustering is an unsupervised classification method, which can classify samples with similar properties without prior knowledge. This paper briefly describes the working principle and performance comparison of these algorithms.

Keywords: Color image segmentation, Fuzzy clustering, Fuzzy C-Means, K-Means.

1. Introduction

On clustering and segmentation is a basic step of image processing. The purpose of this operation is to separate different homogeneous areas in the image, so as to organize objects into groups (clusters) whose members have different common attributes (intensity, color, texture, etc.). Segmentation methods can be divided into two categories: Fuzzy C-Means and K-Means. Firstly, the algorithms of these two methods and their characteristics are introduced. Secondly, the difficulties and defects of Fuzzy C-Means algorithm in image segmentation are analyzed. Finally, we will implement these two algorithms through a series of examples of testing functions realized by MATLAB.

2. Algorithm Description

Fuzzy *C*-Means is the most commonly used image segmentation method based on fuzzy theory and cluster analysis. It is a clustering method based on the idea of partition, which makes the samples belonging to the same area have the greatest similarity through partition, while the samples divided into different areas are the ones with the smallest similarity.

2.1. K-Means

Means algorithm is Fuzzy *C*-Means. The main idea of this algorithm is to divide N samples $x_j(1,2...,n)$ into C groups $G_i(i=1,2...,c)$, so as to minimize the objective function and obtain the cluster center c_i of each group. Usually, the function $d(x_k,c_i)$ is used to represent the dissimilarity between samples, and the objective function is defined as:

$$J = \sum_{i=1}^{c} Ji = \sum_{i=1}^{c} \left(\sum_{k, x_k \in G_i} d(x_k - c_i) \right) \tag{1}$$

When the value of the function $d(x_k,c_i)$ is the Euclidean distance between the sample x_k in group I and the cluster center c_i of the category to which it belongs, the objective function can be expressed as:

$$J = \sum_{i=1}^{c} Ji = \sum_{i=1}^{c} \left(\sum_{k, x_k \in G_i} \left\| x_k - c_i \right\|^2 \right) \tag{2}$$

If c_i is the nearest cluster center to the sample x_j, then x_j belongs to the i-th group. The divided group can be represented by a c×n two-dimensional membership matrix U. When the sample x_j belongs to the i-th group, the element u_{ij} in U is 1, otherwise it takes 0, which can make the objective function J reach the minimum value. If the cluster center c_i is determined, U is determined according to the following formula:

$$u_{ij} = \begin{cases} 1 & k \neq i, \left\| x_j - c_i \right\|^2 \leq \left\| x_j - c_k \right\|^2 \\ 0 & else \end{cases} \tag{3}$$

Since each sample can only belong to one group, u_{ij} should satisfy the following two formulas:

$$\sum_{i=1}^{c} u_{ij} = 1, \ \forall j = 1,..., n \tag{4}$$

$$\sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij} = n \tag{5}$$

If the membership matrix U is determined, then the cluster center c_i of each group that minimizes the objective function J is the average value of the samples in the i-th group expressed by the following formula.

$$c_i = \frac{1}{|G_i|} \sum_{k, x_k \in G_i} x_k \tag{6}$$

Where $|G_i|$ is the number of samples in Group I of the following formula.

$$|G_i| = \sum_{j=1}^{n} u_{ij} \tag{7}$$

Means algorithm is to repeatedly iterate the above process, namely:

Step1: Selecting c values from a sample space as initial clustering centers;

Step 2: Calculate the membership matrix U by Formula 2-3;

Step 3: Find the objective function J from formula 2-2, and when its change is less than a certain threshold, the iteration ends;

Step 4: Get a new cluster center from Formula 2-6, and go to Step 2.

2.2. Fuzzy C-Means

Fuzzy *C*-Means algorithm divides n samples $x_j(1,2...,n)$ into c fuzzy groups $G_i(i=1,2,...,c)$ to minimize the objective function and obtain the cluster center c_i of each group. The difference between it and hard *C* partition is that the Fuzzy *C*-Means algorithm uses the value in the interval [0,1] to indicate the degree to which each sample belongs to a certain group, but the sum of a sample's membership degree to each group must be 1, as follows:

$$\sum_{i=1}^{c} u_{ij} = 1, \forall j = 1,..., n \tag{8}$$

The objective function is changed from Formula 2-2 to the following formula:

$$J(U, c_1,..., c_2) = \sum_{i=1}^{c} J_i = \sum_{i=1}^{c}\sum_{j=1}^{n} u_{ij}^m d_{ij}^2 \tag{9}$$

Where $d_{ij}=||c_i-x_j||$ is the Euclidean distance between the j-th sample x_j and the i-th cluster center c_i; The value of u_{ij} is in the interval [0,1]; The weighted index m=2 is usually taken.

Find each cluster center c_i and each element u_{ij} in the membership matrix U with the minimum value of the objective function J through the functions in the following construction formula.

$$\begin{aligned}\overline{J}(U, c_1,..., c_c, \lambda_1,..., \lambda_n) &= J(U, c_1,..., c_c) + \sum_{j=1}^{n} \lambda_j (\sum_{i=1}^{c} u_{ij} - 1) \\ &= \sum_{i=1}^{c}\sum_{j}^{n} u_{ij}^m d_{ij}^2 + \sum_{j=1}^{n} \lambda_j (\sum_{i=1}^{c} u_{ij} - 1)\end{aligned} \tag{10}$$

Where λ_j (j=1...n) is n Lagrangian factors, and we find the conditions for varying the input parameters to obtain the minimum value of J, that is:

$$c_i = \frac{\sum_{j=1}^{n} u_{ij}^m x_j}{\sum_{j=1}^{n} u_{ij}^m} \tag{11}$$

$$u_{ij} \frac{1}{\sum_{k=1}^{c} \left(\frac{d_{ij}}{d_{kj}} \right)^{2/(m-1)}} \tag{12}$$

Fuzzy *C*-Means algorithm steps are similar to *K*-Means.

Step 1: Initializing the membership matrix U, and taking any value in the interval [0,1] for the elements in U, while meeting the requirements of 2-8;

Step 2: Calculating the CI of each cluster center from 2 to 11;

Step 3: Find the objective function J from 2-9, and when its change is less than a certain threshold, the iteration ends;

Step 4: Get a new membership matrix U from 2-12, and go to step 2.

3. Algorithm Characteristics

K-Means

Advantages: K-Means algorithm is a classical algorithm to solve clustering problems, which is simple and fast; For large data sets, the algorithm is relatively scalable and efficient, because its complexity is about O(nkt), where n is the number of all objects, k is the number of clusters, and t is the number of iterations. Generally k<n . This algorithm often ends in local optimum; The algorithm tries to find out k partitions that minimize the square error function value. When clusters are dense, spherical or clustered, and the difference between clusters is obvious, its clustering effect is very good.

Disadvantages: it is necessary to define the mean value; Specify the number to cluster; Some excessive outliers will have great influence; The algorithm is sensitive to initial value selection; Suitable for spherical clustering.

Fuzzy C-Means

Advantages: Fuzzy C-Means functional Jm is still a natural extension of traditional hard C-Means functional J1. J1 is a widely used clustering criterion, and its theoretical research has been quite perfect, which provides good conditions for the research of Jm. This algorithm has not only been successfully applied in many fields, but also based on this algorithm, fuzzy clustering algorithms based on other prototypes have been put forward, forming a number of Fuzzy *C*-Means algorithms, such as Fuzzy *C*-Line(FCL), fuzzy *C*-plane (FCP), fuzzy *C*-shell (FCS), etc., which respectively realize linear, hyperplane and "thin shell" clustering.

Disadvantages: Although fuzzy clustering is an unsupervised classification, FCM-type algorithm needs to apply the prior knowledge of clustering prototype, otherwise the algorithm will be misleading, thus destroying the unsupervised and automated algorithm.

4. Testing on Matlab

The tests are carried out under Matlab, We compare the two algorithms by the result image.The tests were carried out with a number K of clusters systematically worth 2, 3, 5 and 10. We observed that the best result, both from a point of character detection view than from a time point of view calculation, generally corresponds to the detection of 2 clusters. He seems quite logical that this value of K is the most adequate, since it will be seen in all the images tested, that there are essentially two objects: the background and the characters (numbers and words).

The first image consists of 130x42 pixels. The characters that form the word "study" contain mostly green. The background of the image consists of seve ral shades of blue. The tests on this image give the following results:

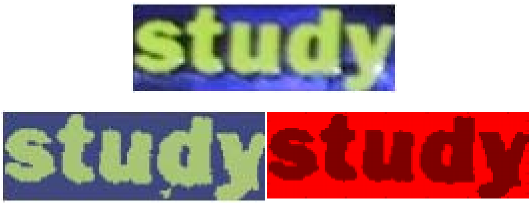

Figure 1. Original image (above), application of Fuzzy *C*-Means (left) and *K*-Means (right) with K=2

The second (75x55 pixels) consists of the numbers “22”. We see that the contours of the figures are very blurred and the part top of image is slightly dark.

Figure 2. Original image (above), application of Fuzzy *C*-Means (left) and K-Means (right) with K=2

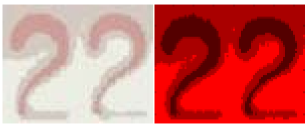

Figure 3. Fuzzy *C*-Means (left) and K-Means (right) with K=3

The dark part of the image makes the use of both different algorithms; on the one hand, with K=2 (Figure 2), we do not clearly distinguish the upper part of "22" and on the other hand, when we increase the number of clusters (example with K=3 in Figure 3), we solve this problem but we then loses detection of the lower part of the "22". This example illustrates that the objects to be segmented must have a sufficiently uniform color so that the detection is possible.

In general, the two algorithms studied give a good result but have two drawbacks: on the one hand, they require the prior choice of the number K of clusters, which makes it impossible to automate the method ; on the other hand, they require computation time often high, due to their iterative nature.

We have seen that these two algorithms turn out to be effective when the objects in the image (essentially the background and characters) are clearly separated.

We measured the execution time of the two algorithms for each image and it appears that FCM is faster for high resolution images and that k means is mo re appropriate in the case of low resolution images. Note that the computation time is never the same for each application of the algorithms, given that it is influenced by the initial position of the centroids, which is calculated randomly.

5. Conclusion

We tested the Fuzzy *C*-Means and *K*-Means segmentations on a series of color images, using Matlab.We found that the two algorithms require prior knowledge of the number of clusters to be determined, which makes it impossible to possible automation of the process. By their character iterative, they turn out to be inefficient when the number of clusters becomes important.

We can therefore conclude that the Fuzzy *C*-Means and *K*-means algorithms are efficient for the detection of characters, but are not appropriate for images containing a large number of objects. From a computation time point of view, FCM turns out to be more efficient for high resolution images. Resolution while *K*-means is more suitable for images of low resolution.

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