SEGMENTATION OF COLOR IMAGES USING A HIERARCHICAL FUZZY REGION MERGING TECHNIQUE

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ABSTRACT

A novel hierarchical clustering method is presented in this work. It operates as a part of a split and merge segmentation scheme. The proposed technique incorporates the use of several color features to compare clusters in the RGB space and the flexibility of the fuzzy reasoning approach to accomplish satisfactory segmentation results. The boundary values of the fuzzy sets have been determined by means of a genetic algorithm optimization approach. The segmentation results evaluated subjectively and objectively were compared to a straightforward product cost function.

1 INTRODUCTION

A region based segmentation technique [1] is presented. All these methods initially produce an oversegmented image [2-4,10,11]. The initial regions are produced using the edge information. Nevertheless, in order to obtain meaningful regions and avoid the oversegmentation (redundant region information) and undersegmentation (lacking region information) effects, an additional clustering approach has to be employed to form the final region map.

In this work the initial segmentation is obtained by a cascade application of a color edge detector, the watershed transform and the waterfall algorithm [5]. In the merging stage, a new mechanism is proposed to measure the dissimilarity between adjacent regions based on fuzzy logic and is accomplished in the following three steps:

1. The spatial interconnection of the N image segments is described using the well-known region adjacency graph (RAG) representation [11]. The image adjacency graph G=(V,E) consists of nodes V={1,2,...,N} and edges Eij where i,j are node indices and E \( \subseteq V \times V \). Each node represents a specific region of the image, while the edge values provide a dissimilarity measurement of adjacent regions.

2. The dissimilarity of the neighboring image segments (i,j) is evaluated in the feature rgb space defining the value of the edge Eij. This computation is carried out by means of a fuzzy reasoning approach. It has the advantage of increased flexibility [6] compared to conventional cost functions, which are simply a product of quantities. The edge values normalized to [0,1] range, are considered to be a dissimilarity measurement of nodes i and j.

3. The method is completed by the formulation of distance matrix, where the dissimilarity as well as the region adjacency are considered. The merging stage is based on the above matrix using a hierarchical clustering technique [7].

2 THE DISSIMILARITY FUNCTION

The Region Adjacency Graph is employed to describe the segmented image. Two adjacent regions are linked by edges Eij and Eji of the graph. The graph in our case is called directed and weighted because Eij \( \neq \) Eji. An example of a region map and it's corresponding adjacency graph are depicted in figures 1 and 2 respectively.

A cost is assigned to each graph edge in order to express the dissimilarity of the neighboring regions. This cost is computed in the RGB space where each region is represented as a cluster of 3D vectors. The cost is found for each pair of clusters based on the following features:

\[
\begin{align*}
v_d &= \left| \mu_i - \mu_j \right| \quad & (1), \\
v_{\text{cd}} &= \cos \left( \frac{\mu_i \cdot \mu_j}{\left\| \mu_i \right\| \left\| \mu_j \right\|} \right) \quad & (2), \\
v_{\text{ac}} &= \left| \sigma_i - \sigma_j \right| \quad & (3), \\
v_{\text{card}} &= \max \left\{ \left| \mu_i \right|, \left| \mu_j \right| \right\} \quad & (4),
\end{align*}
\]

where \( v_d \) denotes the absolute value of the difference of the mean vectors magnitudes (\( \left\| \mu \right\| \) denotes the magnitude of the mean vectors of regions i,j respectively, which is used as estimate of regions.
luminance), \( v_{\Delta \theta} \) denotes the angle between the mean vectors of regions i and j and is a measure of regions color difference. Variable \( v_{d} \) denotes the Euclidean distance of the vectors representing the standard deviations of regions i and j and is a rough estimate of texture divergence and color correlation for the two regions. (At each region, the variance of each channel is computed independently and estimates are used to define a representative vector). The last variable, \( v_{\text{card}} \) (j) denotes the cardinality of region j. This term is utilized to support merging of small regions first. Thus the two adjacent regions, forming clusters in the rgb space, are compared considering the central point location, spread around the center and population.

All the above are considered as fuzzy variables and are described using two fuzzy sets denoted as "small" and "medium". An exception is made for the case of cardinality, where a third set ("very small") is employed.

The following rules describe the inference mechanism which assigns the cost to each edge \( E_{ij} \):

1. if \( v_{\Delta \theta}(\text{small}) \) and \( v_{d}(\text{small}) \) and \( v_{\text{card}}(\text{small}) \) then output(similar).
2. if \( v_{\Delta \theta}(\text{small}) \) and \( v_{d}(\text{small}) \) and \( v_{\text{card}}(\text{medium}) \) then output(probsimilar).
3. if \( v_{\Delta \theta}(\text{small}) \) and \( v_{d}(\text{medium}) \) then output(probnotsimilar).
4. if \( v_{\Delta \theta}(\text{medium}) \) and \( v_{d}(\text{small}) \) then output(probnotsimilar).
5. if \( v_{\Delta \theta}(\text{medium}) \) and \( v_{d}(\text{medium}) \) then output(notsimilar).
6. if \( v_{\text{card}}(\text{small}) \) then output(similar).
7. if \( v_{\text{card}}(\text{medium}_{-}\text{large}) \) then output(notsimilar).

Four fuzzy sets describe the output of the system: "similar", "probably similar", "probably not similar" and "not similar". Defuzzification is performed via the centroid linkage method.

Our next task is to define the parameters of the fuzzy sets assuming trapezoidal shape. Tuning of the fuzzy system is performed by a genetic algorithm optimization technique. Genetic algorithm is an evolutionary stochastic method of identifying the maximum of a function, called the fitness function. The search space is reduced iteratively using three elementary operations: reproduction, crossover and mutation. The algorithm converges after a specific number of iterations, which are called generations.

The input variables of the genetic algorithm are the parameters (boundary values) of the fuzzy sets. The fitness function in our case will be related to a segmentation evaluation function. The latter quantifies the accuracy of segmentation. Several functions have been presented (see references in [8,9]. For this purpose, we selected the cost function presented in [8] that is given by the relation:

\[
G_{\text{cost}} = \sum_{i=1}^{N} \left( \frac{1}{\text{card}_i} \right) \end{equation}

where \( N \) denotes the number of regions of the image, \( h \) the height and \( w \) the width of the image, \( \text{card}_i \) the standard deviation vector of region i, and \( \text{card} \), the cardinality of region i.

The corresponding fitness function is:

\[
F = c - G_{\text{cost}} \end{equation}

where \( c \) is a user-defined constant.
3 THE MERGING PROCESS

Having defined the edge cost \( E_{i,j} \), a distance matrix \( D_{i,j} \) is formed with elements:

\[
\begin{align*}
D_{i,j} &= E_{i,j} & \text{if } i,j \text{ are neighbors} \\
D_{i,j} &= 1 & \text{otherwise}
\end{align*}
\]

The above matrix provides information both for the cost and the adjacency of regions \( i,j \). In figure 3 an example of the distance matrix is displayed for the regions of figure 1. Each column \( j \) of the matrix represents the cost of merging region \( j \) to its adjacent regions. The minimum value of each column contains the cost of merging region \( j \) to its nearest neighbor and indicates the most similar pair of regions. The minimum value of all the columns represents the most similar pair of regions. The former regions are merged first. Consequently, the region adjacency graph is reconstructed by means of finding the neighbors of the resulting region and updating the cost matrix. The latter is accomplished by erasing row \( j \) and column \( j \) and calculating the new costs of region \( i \) (row \( i \) and column \( i \)).

The above process is repeated iteratively as long as the merging criterion is satisfied that is, the number of regions is above a specific threshold. In this manner, the merging sequence is created stepwise.

4 RESULTS AND CONCLUSIONS

The proposed method has been applied to a variety of color images. The result of the overall process for image ‘teeny’ is illustrated in figure 4a. From a subjective point of view the final partition corresponds to meaningful regions. It is worth noting that small regions of important details such as the eyes and the lips are retained due to the flexibility of the fuzzy reasoning. This statement becomes more obvious when results are compared to those of a segmentation scheme that uses the same features but in a product cost function [10]. This is referred to as “crisp analogous”, and results for the same number of final regions are illustrated in figure 4b.

![Figure 4](image)

Figure 4. Regions resulting from (a) fuzzy cost evaluation, (b) crisp analogous.

The fuzzy approach still gives better results when it is evaluated using as objective criteria (i) the Peak Signal to Noise Ratio between the original image and the first order approximation of the segmentation result and (ii) the number of contour points displayed (see table 1). The PSNR is an evaluation of segmentation quality, while the number of contour points is indicative of the information redundancy and the efficiency of segmentation in terms of compression.

In conclusion, the proposed work is a hierarchical clustering method, which is integrated in a hybrid segmentation scheme. This method exploits the advantages of a fuzzy inference system, which proved to be quite effective for determining a suboptimum solution of the merging sequence. It is also worth noting that the notion of “modified distance matrix”, which is referred in the merging procedure, contains information about the nearest neighbor of each region.

Our future objectives include a fast implementation of the merging stage, the design of a region based color image compression scheme based on the proposed fuzzy segmentation method and a perceptual segmentation method in a different color space.
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Table 1

References


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\(^1\) PCF stands for Product Cost Function
\(^2\) FDE stands for Fuzzy Dissimilarity Estimation