Color Image Segmentation
An Innovative Approach

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Abstract

- Color image segmentation
  - Color clustering *in a color space*
    - Fuzzy clustering algorithm
  - Color region segmentation *in the image domain*
    - Three clustering algorithms
Color Image Segmentation System

Overview of the color image segmentation

Stage 1: Color segmentation
- Compute 3D histogram in a color space
- Fuzzy clustering in color histogram domain
- Fuzzy membership function
- Color distances between the neighboring regions

Stage 2: Region segmentation
- Map initial clusters to image domain
- Merging neighboring clusters
- Region sizes and maximum number of clusters

A set of color regions

Fig. 1. An overview of the color image segmentation.
A Fuzzy Clustering Algorithm for Color Segmentation

- **Color histogram of an image**
  - $f(C)$: The number of pixels, $C$: A color in the image

- **Fuzzy clustering algorithm**
  - Fuzzy set
    - A cluster of similar colors
  - Fuzzy membership function
    - The likeness of a color pixel belonging to a fuzzy set
Two critical issues involved in a fuzzy membership function

- Generating fuzzy membership functions
  - The likeness of a data element belonging to a color cluster

- Defining a color distance function
  - Between two color clusters
  - Between a color and a color cluster
Fuzzy membership function

- Gaussian function

- The probability if a color \( C \) belonging to a color cluster

  \[ G_R(C - P) = e^{-\|C - P\|^2 / R^2} \]

  - \( P \): The center of the cluster
  - \( R \): The radius of the cluster

- The probability of a color belonging to the k-th cluster and not belonging to any other cluster

  \[ H_k(C; P_1, \cdots, P_M) = G_R(C - P_k) \prod_{i \neq k} [1 - G_R(C - P_i)] \]
– **Important characteristics** of fuzzy membership function

- Belief value decreases as the distance between a color $C$ and a color cluster $P$ increases
- Belief value of a particular color belonging to a cluster depends on its relationship with other clusters
- Belief value of a color belonging to a cluster is always greater than zero
Cluster separability

- How well a given n-cluster description matches a given set of data
- Objective function
  - A mean square error over the inter and intro distances of all color clusters
    \[
    F(P_1, \cdots, P_M) = \sum_{k=1}^{M} \sum_{C_i} f(C_i) \cdot H_k(C_i; P_1, \cdots, P_M) \cdot \|C_i - P_k\|^2
    \]
  - Ex) In the case when there is only one cluster (R is radius of cluster)
    \[
    F(P) = \sum_{C_i} d(C_i - P) = \sum_{C_i} \|C_i - P\|^2 \cdot G_R(C_i - P)
    \]
  - \|C_i - P\| = R: Large mean square error \rightarrow Largest uncertainty
– Optimization process

- $C_k$: Initial center of cluster 1, \( t=0 \), \( P_M^0 = C_k \)

- \[
P^{t+1}_M = \frac{\sum_{c_i} C_i \cdot f(C_i) \cdot H_M(C_i; P_1, \ldots, P_{M-1}, P^t_M)}{\sum_{c_i} f(C_i) \cdot H_M(C_i; P_1, \ldots, P_{M-1}, P^t_M)}
\]

- \( \delta \): The threshold of the difference between a cluster center and the cluster center at the previous iteration

- If \( \|P^t_M - P^{t+1}_M\| > \delta \) , compute a new center

- If \( \|P^t_M - P^{t+1}_M\| \leq \delta \) , accept as the center of the cluster
– Optimization process (Generating a new cluster)

\[ f(C_k)V(C_k; P_1, \cdots, P_M) \leq \varepsilon \sum_{C_k} f(C_k) \]

\[ V(C; P_1, \cdots, P_M) = \prod_{k=1}^{M} [1 - G_R(C - P_k)] \]

- The probability of a color not belonging to any existing cluster
- \( \delta \) controls the number of iterations in optimizing a new cluster center
- \( \varepsilon \) determines when to stop generating new clusters
- \( R \) is the cluster radius
- **Cluster radius** $R$
  - How much the clusters can overlap with each other

- **Color clustering results**

Fig. 2. Color clustering results with different cluster radii on an image with simple features: (a) original image, (b) $R=64$, (c) $R=32$, (d) $R=16$, and (e) $R=8$. 
Image Segmentation in Image Space

- Region Segmentation algorithm in image domain
  - Color similarity and spatial adjacency
  - Important parameters in the image domain
    - The color distances among neighboring clusters in the spatial domain
    - Cluster sizes
    - The maximum number of clusters in CL3
Merging process

- The order of merging clusters

- **Method 1**
  - Merge the neighboring clusters whose color distances are below threshold
    - No consideration of the order of merging
  - Select the smallest cluster and merges the cluster with one of its neighbors to which it has the smallest color distance

- **Method 2**
  - Selects the smallest cluster and merges the cluster with one of its neighbors to which it has the smallest color distance
– **Method 3**

- Repeatedly merges the smallest clusters with the neighbors
- Selects a pair of two adjacent clusters that has the smallest color distance within the entire image to merge
- Merges the smallest cluster with its closest neighbor in color distance
Two functions for computing the color distance

- Color difference of the border pixels of clusters A and B

\[ B\_\text{Dist}(A, B) = |Ave\_B(A) - Ave\_B(B)| \]

Fig. 2. Illustration of border points between region A and B.
The central color of a cluster

\[ C_A = \frac{\sum_{p \in A} C(p)}{|A|} \]

- \( p \) is a pixel \( \in A \),
- \(|A|\) is the size of \( A \),
- \( C(p) \) is the 3-D color vector
Fig. 3. Comparison of clustering results generated by three different spatial merging methods: (a) shows an egg nebula image, (b) shows the clusters generated by the fuzzy clustering algorithm with $R=16$, (c), (d), and (e) show the clustering result generated by method 1, 2, and 3, respectively, from (b).