A Study on Color Space Selection for Determining Image Segmentation Region Number*

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Abstract *When image segmentation is treated as a problem of clustering color pixels, the finite mixture model with EM algorithm can be used to cluster color space samples. With estimated mixture model parameters, we adopt the BYY model selection criterion to determine how many regions should be segmented on a given color image. In this paper, we experimentally investigate the effect of choosing different color space for determining a reasonable region number based on the BYY criterion.*

Keywords: Image Segmentation Region Number, Finite Mixture Model, BYY Model Selection Criterion, EM algorithm, Color Space.

1 Introduction

Image segmentation is to partition a given image into some meaningful regions and label each region by a region type. There are a wide variety of image segmentation techniques[1]. Feature space clustering is among the most popular of these methods. A clustering method is used to group the points in the feature space into clusters. These clusters are then mapped back to the original spatial domain to produce a segmentation of the image.

When image segmentation is viewed as a clustering process, several techniques exist for clustering. Among the clustering techniques, the finite mixture of distribution, in particular normal (Gaussian) mixture, has been used in a wide variety of important practical situations. The maximum likelihood approach to the fitting of finite mixture models has been utilized extensively[2]. Because of its advantage, the cluster analysis with finite mixture model has attracted considerable interest for image segmentation in recent years[3, 4, 5].

In fact, in the feature-space clustering method for image segmentation, the number of segments to be yielded can be considered as the number of clusters, k, in the feature space. Usually, k has to be specified in advance. If k is correctly selected, good clustering result can be achieved; otherwise, data points cannot be grouped into appropriate clusters and image segmentation cannot be performed appropriately. To determine a reasonable region number is one of the difficult things in machine learning. This problem affects the ability to automatically interpret images by a machine, which has been one of the major challenges in computer vision. In the past, most of the work used a pre-assigned number or some heuristics to determine the number of regions.

A Bayesian-Kullback scheme, called the Ying-Yang Learning Theory and System (BYY), or Ying-Yang machine, has been proposed recently to act as a general learning scheme for unifying the existing major unsupervised and supervised learning[6, 7]. One special case of the Ying-Yang machine can provide us the criterion for determining appropriate cluster number in clustering[8]. The experimental simulation results in [8, 9] have shown

*The work described in this paper was supported by a grant from the Research Grant Council of the Hong Kong Special Administrative Region (Project No. CUHK4432/99E).

that obtained criterion works well in determining cluster number. If we assume that the number of regions in image spatial domain is equal to the number of clusters in color space, with this BYY model selection criterion we can determine how many regions should be segmented[10]. Apparently, the distribution of clusters depends on the color space selection, therefore, the determined region number is variable for different color space. In this paper, we investigate the effect of color space selection on the region number determination problem.

2 Background

When an image was given, assuming the image has N pixels, we use x_i to denote the observation at the ith color pixel. The whole samples in the image form data set $D = \{x_i\}_{i=1}^N$, assuming that x_i is a sample from a finite mixture distribution.

In the following we will briefly review the Gaussian finite mixture model with EM algorithm, and the BYY model selection criterion.

2.1 Finite Mixture Model and EM Algorithm

Considering a Gaussian finite mixture model, the joint density, which consists of k component Gaussian density, in feature space is denoted by

$$\begin{aligned} P(x, \Theta) &= \sum_{y=1}^{k} \alpha_y G(x, m_y, \Sigma_y), \\ \text{with} \quad \alpha_y &\geq 0, \text{ and } \sum_{y=1}^{k} \alpha_y = 1 \end{aligned} \quad (1)$$

where

$$G(x_i, m_y, \Sigma_y) = \frac{\exp[-\frac{1}{2}(x_i - m_y)^T \Sigma_y^{-1} (x_i - m_y)]}{(2\pi)^{d/2} |\Sigma_y|^{\frac{1}{2}}} \quad (2)$$

is a general expression of multivariate Gaussian distribution. x_i denotes a random vector, d is the dimension of x, and the parameter $\Theta = \{\alpha_y, m_y, \Sigma_y\}_{y=1}^k$ is a set of finite mixture model parameter vectors. Here α_y is the mixing weights, m_y is the mean vector, and Σ_y is the covariance matrix of the yth component of the mixture model. Actually, these parameters are unknown, and using how many Gaussian component densities can best describe the joint probability density is also unknown. Usually with a pre-assigned number k, the mixture model parameters are estimated by maximum likelihood learning (MLE) with ordinary EM algorithm [11, 2].

EM algorithm for estimating mixture model parameters can be described as follows:

E-step:

$$\begin{aligned} p(y|x_i) &= \frac{\alpha_y G(x_i, m_y, \mathbf{\Sigma}_y)}{\sum_{y=1}^{k} \alpha_y G(x_i, m_y, \mathbf{\Sigma}_y)}, \\ \text{with } y &= 1, ..., k, \end{aligned} \quad (3)$$

M-step:

$$\alpha_y^{new} = \frac{1}{N} \sum_{i=1}^{N} p(y|x_i)$$

$$m_y^{new} = \frac{\sum_{i=1}^{N} p(y|x_i) x_i}{\sum_{i=1}^{N} p(y|x_i)} \quad (4)$$

$$\mathbf{\Sigma}_y^{new} = \frac{\sum_{i=1}^{N} p(y|x_i)[(x_i - m_y^{old})(x_i - m_y^{old})^T]}{\sum_{i=1}^{N} p(y|x_i)}.$$

With this iterative EM algorithm, the mixture parameters can be estimated based on samples in color space.

Each component of the finite mixture is regarded as one cluster. After parameters learning, the *posterior* probability $p(y|x_i)$ represent the probability that data point x_i belongs to cluster y. Now we use Bayes decision $y^* = \arg\max_y p(y|x_i)$ to classify x_i into cluster y^*. This procedure is called Bayesian probabilistic classification.

2.2 Model Selection Criterion

There exist some theoretical information criteria which can be used to select the number of models, such as AIC[12], AICB [13], CAIC

[14], SIC [15]. In this work, we adopt the BYY model selection criterion.

As stated in [6, 7], unsupervised and supervised learning problems can be summarized into the problem of estimating joint distribution $P(x, y)$ of patterns in the input space $\mathbf{X}$ and the representation space $\mathbf{Y}$. Based on the situation considered in [8], we have the following BYY model selection criterion in the Gaussian mixture model case,

$$J_1(k, \Theta^*) = \frac{1}{N}\sum_{i=1}^{N}\sum_{y=1}^{k} p(y|x_i)\ln p(y|x_i) + \frac{1}{2}\sum_{y=1}^{k}\alpha_y^* \ln|\Sigma_y^*| - \sum_{y=1}^{k}\alpha_y^* \ln \alpha_y^*.$$

$$J_2(k, \Theta^*) = \frac{1}{2}\sum_{y=1}^{k}\alpha_y^* \ln|\Sigma_y^*| - \sum_{y=1}^{k}\alpha_y^* \ln \alpha_y^*. \quad (5)$$

With the above $J(k, \Theta)$, we can select the cluster number k^* simply by $k^* = \arg\min_k J(k, \Theta^*)$ with MLE obtained Θ^*. In practice, we usually start with $k = 1$, estimate parameter Θ^*, and compute $J(k = 1, \Theta^*)$. Then by setting $k \to k + 1$, we compute $J(k = 2, \Theta^*)$ and so on. After getting a series of $J(k, \Theta^*)$, we choose the minimal one and get the corresponding k^*. This k^* is assumed to the number of regions where an image should be segmented.

2.3 Bayesian Probabilistic Classification

When an image with N pixels was given, we use $\mathbf{x}_i$ to represent a random feature vector in feature space for pixel i. For example, in RGB color space, $\mathbf{x}_i = \{R_i, G_i, B_i\}$ is a three dimensional vector, and the components of $\mathbf{x}_i$ stands for Red, Green, Blue color value of pixel i of an image respectively, where $i = 1, 2, \ldots, N$. These vectors can be regarded as identical independent distribution. After we got k^* with BYY criterion and the mixture model parameter Θ^* with EM algorithm, we can calculate the posterior probability that sample $\mathbf{x}_i$ belongs to cluster y. From Bayes rule, the posterior probability is written in the form of equation (3).

For given $\mathbf{x}_i$, we can obtain k probability $p(y = 1|\mathbf{x}_i)$, $p(y = 2|\mathbf{x}_i), \cdots, p(y = k|\mathbf{x}_i)$, we use the Bayes decision to classify pixel i into cluster y by the solution if $y^* = \arg\max_y p(y|\mathbf{x}_i)$, for $y = 1, 2, \cdots, k$, pixel i will be classified to cluster y^*. Therefore, the finite mixture model image segmentation is a pixel classification procedure.

2.4 Color Space

A color image is represented by three components, such as RGB, XYZ, YIQ, HSI and so on[16]. Which color space is suitable for clustering and how it affects the proper region number determination? There is no theoretical guide for this quite new problem, and we believe that the probable answer should be based on experimental testing.

In this paper, we concentrate on the following color spaces.

(1) RGB (Original tristimuli Red, Green, and Blue): this color space is used for display.

(2) YIQ: for color system of TV signal.

(3) XYZ: for C.I.E X-Y-Z color system.

(4) $X_1X_2X_3$: this color feature is obtained by Karhunen Loéve transformation, also called PCA. X_1, X_2, X_3 are uncorrelated with each other.

(5) $I_1I_2I_3$: for uncorrelated features.

(6) HSI (Hue, Saturation and Intensity): for human perception.

Relations of the above color systems with RGB are as the following. Note the transformation matrices are not the standard ones[16].

(a) YIQ

$$\begin{aligned} Y &= 0.299R + 0.587G + 0.114B \\ I &= 0.5R - 0.23G - 0.27B \\ Q &= 0.202R - 0.5G + 0.298B \end{aligned} \quad (6)$$

(b) XYZ

$$\begin{aligned} X &= 0.618R + 0.177G + 0.205B \\ Y &= 2.299R + 0.587G + 0.114B \\ Z &= 0.056G + 0.944B \end{aligned} \quad (7)$$

(c) $\mathrm{I_1I_2I_3}$

$$
\begin{aligned}
I_1 &= (R+G+B)/3 \\
I_2 &= (G-B)/2 \\
I_3 &= (2G-R-B)/4 \qquad (8)
\end{aligned}
$$

(d) HSI

$$
\begin{aligned}
H &= \arctan\left(\frac{\sqrt{3}(G-B)}{2R-G-B}\right) \\
S &= 1-\frac{\min(R,G,B)}{R+G+B} \\
I &= R+G+B \qquad (9)
\end{aligned}
$$

(e) $\mathrm{X_1X_2X_3}$

$$
\begin{aligned}
X_1 &= w_{R1}R + w_{G1}G + w_{B1}B \\
X_2 &= w_{R2}R + w_{G2}G + w_{B2}B \\
X_3 &= w_{R3}R + w_{G3}G + w_{B3}B \qquad (10)
\end{aligned}
$$

where $W_i = (w_{Ri}, w_{Gi}, w_{Bi})$, $i = 1,2,3$ are three eigenvectors of Σ, $\Sigma W_i = \lambda_i W_i$, λ_i is eigenvalue, and

$$
\begin{aligned}
m &= \frac{1}{N}\sum_{i=1}^{N} x_i(R,G,B) \qquad (11) \\
\Sigma &= \frac{1}{N}\sum_{i=1}^{N}(x_i-m)(x_i-m)^T \qquad (12)
\end{aligned}
$$

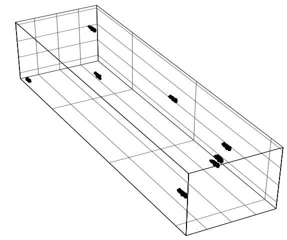
With these relation equations, other color spaces are transformation of RGB color space.

3 Experiments

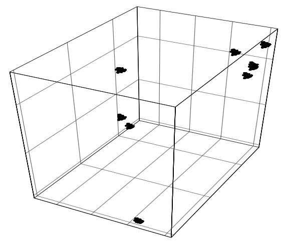
In the experiments, we use one synthetic image and some standard images such as "house" and "sailboat" to test the effect of color space selection on the BYY model selection criterion. Each image is a 24-bit color map with the size of 128×128 pixels.

Choosing a different color space will result in different shape and distribution of clusters, which leads to an estimated parameter variable, though the EM algorithm and classification rule is the same for all color spaces. In the experiments, with the selected color space, we

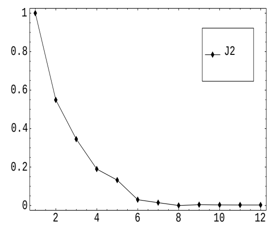
(a) Synthetic image



(b) $X_1X_2X_3$ color space



(c) RGB color space

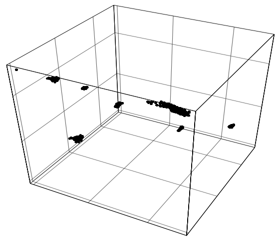


(d) $J_2 - k$ curve for RGB space, $k = 8$ is correct selected.

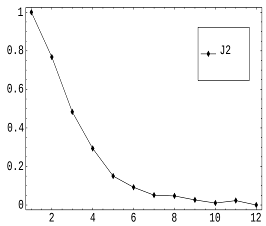
Figure 1: Synthetic image with 8 regions, as well as some color spaces, $J_2 - k$ curve for determining the segment region number. $J_2 - k$ curves for $\mathrm{X_1X_2X_3}$, XYZ and $\mathrm{I_1I_2I_3}$ color systems are similar to RGB's.

run the EM algorithm to estimate mixture parameters and compute $J(k, \Theta^*)$ curves. In order to eliminate the influence of EM algorithm converging to different local minima, we repeat the experiment with same condition but with different initial parameter value several times, then use the most probable results.

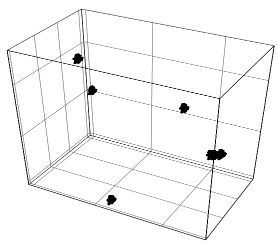
Several experiments have been done. Here only parts of experimental result for synthetic image are shown in Figure 1. Similar results are observed for "house" and "sailboat" images. In the synthetic image, there are 8 colors, and each color represents one cluster in a color space. If colors are similar for some classes, clusters will overlap in the HSI or YIQ color space. Overlapping has an influence on proper



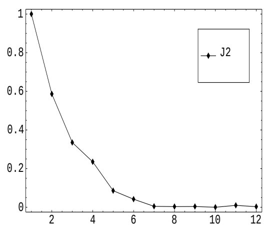
(a) Scaled HSI color space



(b) $J_2 - k$ curve for HSI space, it over estimates region number.



(c) Scaled YIQ color space



(d) $J_2 - k$ curve for YIQ space, it under estimates region number.

Figure 2: Some color space for the synthetic image with 8 regions, as well as $J_2 - k$ curve for determining the segment region number. $J_2 - k$ curves for $X_1X_2X_3$, XYZ and $I_1I_2I_3$ color system are similar to RGB's.

clustering: it results in a poor region number selection.

In the experiments, it is found that using RGB, XYZ, $X_1X_2X_3$ and $I_1I_2I_3$ color spaces yields the same reasonable region number. In $X_1X_2X_3$ or $I_1I_2I_3$ color space, it is easy to cluster with EM algorithm and the computation time is also less than using HSI color space. Hue is unstable when Saturation is near zero, in which case, it would be very difficult to correctly determine the region number and segmentation. On the other hand, based on the experimental testing, the final choice of color space is $X_1X_2X_3$ or $I_1I_2I_3$ system. This is because $X_1X_2X_3$ or $I_1I_2I_3$ color coordinates are almost uncorrelated, and they are effective for region number determination based on the BYY model selection criterion.

From the experiments, we know that by using the BYY model selection criterion, as long as the proper color space is used, in most cases we can select a reasonable region number, and make it possible in automatic segmenting a given image without *a priori* knowledge.

4 Summary

In this paper, we have investigated the effect of color space selection on determining image segmentation region number based on the BYY model selection criterion. Six color spaces have been tested and compared experimentally. EM algorithm was used to estimate mixture model parameters and Bayes decision rule was used to classify pixels into a proper region.

In conclusion, RGB space is the basic selection while $X_1X_2X_3$ or $I_1I_2I_3$ color space is more appropriate for clustering in this BYY model selection criterion application.

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