Circular Histogram Thresholding For Color Image Segmentation

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Abstract

A circular histogram thresholding for color image segmentation is proposed. A circular hue histogram is first constructed based on a UCS *(I,H,S)* color space. The histogram is automatically smoothed by a scale-space filter, then transformed into traditional histogram form, and finally recursively thresholded based on the maximum principle of variance. Three comparisons of performance are reported: (i) the proposed thresholding on the circular histogram with that on a traditional histogram; (ii) the proposed thresholding with clustering; and (iii) thresholding based on a UCS hue attribute with that based on a non-UCS hue attribute. Benefits of the proposed approach are confirmed in the experiments.

1. Introduction

A lot of attention has been focused on segmentation of intensity images. The segmentation results are poor when the images are partially highlighted or shaded in a few of uniform regions. It has been long known that, due to brightness adaptation, the human eye can only detect a few dozen intensity levels in a complex image, but can recognize thousands of chromatic variations [1]. Using color attributes to segment images should get better results since these attributes are less dependent on object position and are more easily separated than intensity attribute.

In this paper, circular-histogram thresholding is proposed to segment color images based on a UCS (uniform chromaticity scale) perceptual color space. The proposed approach consists of four steps:

1. Extract chromatic pixels of an image based on a 3-D UCS *(I,H,S)* color space to construct a circular hue histogram;
2. Smooth the circular hue histogram using a *scale-space filter*;
3. Transform the circular histogram into traditional histogram form;
4. Multi-threshold the histogram based on the maximum principle of variance.

2. Preliminary

Color spaces and the concept of circular histogram are described in this section.

2.1 Color spaces

To match human-eye sensitivity by computer, a mathematical expression is necessary to measure color difference as perceived by humans in Euclidean distance. A system represented by such a mathematical expression is called the uniform chromaticity scale (UCS) system [2]. CIE transformed (X,Y,Z) space into (L^*,a^*,b^*) and (L^*,u^*,v^*) spaces to approximate the properties of the uniform chromaticity scale for color difference evaluation. Since (L^*,u^*,v^*) space is the newer system and seems to better approximate color difference sensed by human eyes [2], we use this color space in this study. Every color is represented by a point in (L^*,u^*,v^*) space and the color difference is measured by the simple Euclidean distance.

(I,H,S) color space is a perceptual color space. The attributes of intensity, hue and saturation are psychological attributes related to human perception of color. Using perceptual color space to specify and control color is more like human intuition, and to independently control intensity or chromatic component is more easy [3].

To use a perceptual color space possessing the advantages of UCS, the (L^*,u^*,v^*) space is transformed to an *(I,H,S)* space. Such a UCS perceptual color space is suitable for color image segmentation, because we can utilize it to process each component individually. As with other color spaces, not all perceptual components of a UCS color space are useful for color-image segmentation. Hue is the most useful attribute providing sufficient information for color segmentation, but it is meaningless when the intensity is very high or very low. Thus, we must specify a useful hue range for processing to reduce poor segmentation results.

2.2 Circular histograms

Histograms provide very useful information for image segmentation. The positions of peaks and valleys usually indicate the existence of smooth areas and edges. If we discover the information embedded in histogram more effectively, we will process the image more accurately.

In a traditional gray-level histogram, the horizontal axis represents gray level and the vertical axis represents the number of pixels. Two extremes on the horizontal axis denote the most black and the most white gray levels, respectively; these two coordinates indicate the largest gray-level difference.

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A perceptual color space *(I,H,S)* is a 3-D cylindrical coordinate system $[r, \theta, z]$; the attribute H is represented by the coordinate θ in the range [0°, 359°]. That is, hue is a periodic function of angles with period 360°. Hues $H(0^\circ)$ and $H(359^\circ)$ have only a small difference; however, if we directly represent a hue histogram as a traditional histogram, we will lose the periodic property of the hue attribute such that a single cluster will be separated into two meaningless clusters.

In the past, a few researchers used the hue histograms to segment color images [3, 4, 5], but they did not consider its periodic property. We here propose a novel histogram representation called circular histogram as shown in Fig.1(b) to embed the hue periodic property. In the circular histogram, a radius r indicates the number of pixels and an angle θ indicates a certain hue value.

3. Circular Histogram Thresholding

Histogram smoothing and histogram thresholding are proposed in this section.

3.1 Histogram smoothing

Most histograms of nature-scene images are not smooth enough and contain many rugged peaks that would confuse our analysis. A scale-space filter proposed by Witkin [6] and based on the Gaussian function is employed to smooth histograms. Assume a continuous histogram $f(x)$, then the smoothed histogram is

$$F(x,\sigma) = f(x) * g(x,\sigma) = \int_{-\infty}^{\infty} f(u) \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-u)^2/2\sigma^2} du \, , \quad (1)$$

where g is the Gaussian function with a specific standard deviation σ, and $*$ denotes a 1-D convolution. The standard deviation of σ is the scale of the filter.

In the filter, a large scale σ will cause more significant smoothing, but will also lose much detail information; a small σ will cause insufficient smoothing. Choosing an appropriate scale is critical to successful use of the scale-space filter. In this study, we use the circular histogram entropy to determine the scale σ automatically. The entropy is small when the histogram is ragged, and increases the histogram gets smoother. The entropy is given as

$$E = \sum P_i \log_2 P_i \, , \quad (2)$$

where P_i is the percentage of pixels with hue value i.

3.2 Threshold criteria

Thresholding on a circular histogram is different from that on a traditional histogram. We here propose circular-histogram thresholding based on maximizing the between-class variance and minimizing the within-class variance in the histogram. Assume that a histogram is thresholded into k classes. The sum of squares of the entire histogram is given by

$$SS_T = \sum_i^k \sum_j^{n_i} (x_{ij} - \bar{x})^2 \, , \quad (3)$$

where n_i is the number of pixels in the ith class, x_{ij} is the hue value of the jth pixel in the ith class and $\bar{x}$ is the hue-value mean of the entire histogram. The sum of squares, SS_T, can be divided into two terms, called the sum of squares between-class and within-class:

$$\begin{aligned} SS_T &= \sum_i^k \sum_j^{n_i} (x_{ij} - \bar{x}_i)^2 + \sum_i^k \sum_j^{n_i} (\bar{x}_i - \bar{x})^2 \\ &= \sum_i^k \sum_j^{n_i} (x_{ij} - \bar{x}_i)^2 + \sum_i^k n_i (\bar{x}_i - x)^2 \, , \\ &= SS_w + SS_b \end{aligned} \quad (4)$$

where SS_b is the sum of squares between-class and SS_w is the sum of squares within-class. The mean squares of SS_b and SS_w are denoted by MS_b and MS_w:

$$MS_b = \frac{SS_b}{k-1} \quad \text{and} \quad MS_w = \frac{SS_w}{N-k} \, ,$$

where N is the total number of pixels. *F-value* is defined on the mean squares,

$$F = \frac{MS_b}{MS_w} \, , \quad (5)$$

to determine threshold values.

A two-class *F-value* is used in the proposed circular-histogram thresholding. In multi-thresholding, threshold values are determined one by one based on the maximum *F-value* subject to two criteria: number of pixels and location of threshold value, to avoid an image being subdivided into small and meaningless subregions:

Criterion I : Number of pixels. The number of pixels in a subregion must be larger than a constant n that depends on the size of the image.

Criterion II : Location of threshold value. The location of a threshold candidate in a subregion must be far enough from the extremes of the subregion.

A hue value is selected to be a threshold candidate if it has the maximum *F-value* subject to the above criteria, and then taken as a threshold value if the maximum *F-value* is greater than a pre-defined constant γ.

3.3 Thresholding

Before histogram thresholding, the circular hue histogram is first expanded to traditional histogram form by cutting at the location of $H(0^\circ)$. Next, we compute a

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F-value for every hue value, take the hue value possessing the maximum *F-value* to be a cut point, and separate the histogram into two subregions at this point. We then exchange these two subregions to obtain an appropriate histogram for thresholding. An example is shown in Fig.2. In Fig.2(a), T is the selected cut point of the histogram; the histogram is divided into two subregions and then these two subregions, classes I and II, are exchanged as shown in Fig.2(b).

The transformed histogram is recursively thresholded by the bi-section method based on the maximum principle of variance.

The thresholding is summarized as follows:

1. Smooth the hue histogram by a scale-space filter with histogram entropy.
2. Expand and transform the hue histogram into traditional histogram form based on the maximum *F-value.*
3. Find a hue value possessing the maximum *F-value* subject to *Criteria I* and *II* in a region or subregion.
4. If the maximum *F-value* is greater than the constant γ, then the hue value is taken to be a threshold value to segment the region or subregion into two subregions. Go to Step 3. If no remaining subregion need segmentation, then stop the procedure.

4. Experiments and Discussions

Thresholded results and three comparisons of performance are reported here. Twenty-six images were used to evaluate the performance of the proposed thresholding, of which three are illustrated here.

A path image is shown in Fig.3(a). The thresholded result of a traditional histogram is given in Fig.3(b), and that of the circular histogram is shown in Fig.3(d). The path region in Fig.3(b) is forcibly separated into two clusters and a more complete path region is shown in Fig.3(d). The selected threshold values from the traditional and circular histograms are shown in Figs.3(c) and (e), respectively.

A 3-D clustering using UCS (I,H,S) data and a 1-D clustering using UCS circular hue histogram were carried out to compare the proposed approach. The k-mean algorithm was used for the clustering processes. In the 3-D clustering, the color difference between two points (I_1,H_1,S_1) and (I_2,H_2,S_2) is defined as

$$d=(d_I+d_C)^{1/2} \qquad (6)$$

with

$$d_I=(I_1-I_2)^2 \text{ and } d_C=S_1^2+S_2^2-2S_1S_2\cos\theta$$

where

$$\theta=|H_1-H_2|, \qquad \text{if } |H_1-H_2|\leq 180^\circ$$
$$=360^\circ-|H_1-H_2|, \text{ if } |H_1-H_2|>180^\circ.$$

The color difference for the 1-D clustering is defined by the hue value alone. A fruit image is shown in Fig.4(a). The segmented results using 3-D clustering, 1-D clustering and the proposed thresholding are shown in Figs.4(b), (c), and (d), respectively. The 3-D clustering reveals the best segmentation result, next is the proposed approach, and the 1-D clustering is last. However, the 3-D clustering takes 471 seconds, the 1-D clustering 109 seconds, and the proposed approach only 4.34 seconds for the entire segmentation process.

The proposed thresholding approach has been applied to UCS and non-UCS hue histograms. The thresholded results of a flower image are shown in Fig.5. The flower region is diffuse and the background is messy as shown in Fig.5(c), this is obtained from a non-UCS hue histogram. The thresholded result based on a UCS attribute is obviously superior to one based on a non-UCS attribute.

Several experimental results have been illustrated. From these experiments, a few comments are given:

(i) Circular histograms always yield better segmentation results than traditional histograms.

(ii) Although clustering may obtain the best segmented results in most cases, it is a time-consuming process. Even if a 1-D clustering is used, the processing time is about twenty-five times longer than that of the proposed approach. Moreover, the segmented result using the proposed thresholding approach may be not as good as that of 3-D clustering, but it is slightly superior to that obtained by 1-D clustering.

(iii) The perceptual attributes of a UCS color space are more appropriate than those of a non-UCS color space for color-image segmentation.

(iv) The criterion of the maximum principle of variance is suitable for multi-thresholding. It is more easily implemented than sharpness function [4].

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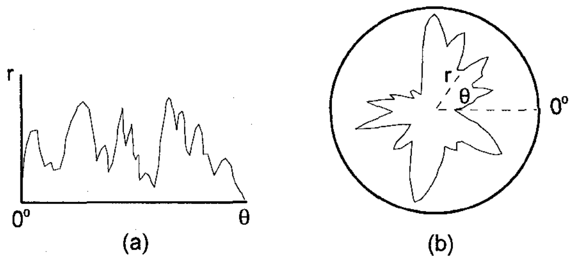

Fig. 1. (a) A histogram; (b) a circular histogram.

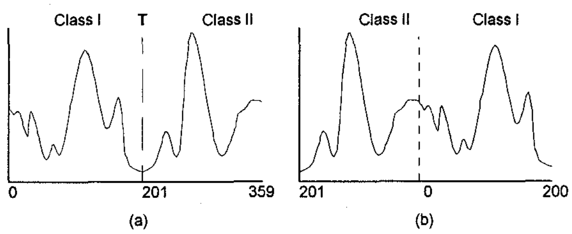

Fig. 2. (a) The original histogram; (b) a transformed histogram based on the circular histogram characteristics.

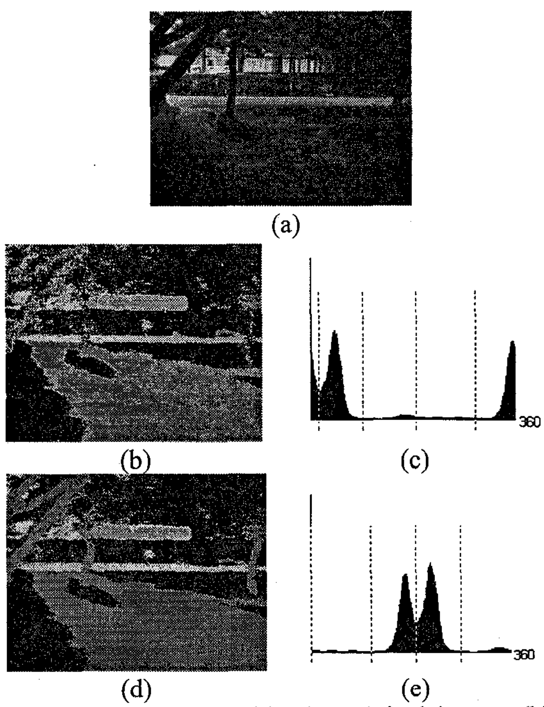

Fig. 3. A path image. (a) The original image; (b) the thresholded result from the traditional histogram; (c) the threshold values on the traditional histogram; (d) the thresholded result from the circular histogram; (e) the threshold values on the circular histogram.

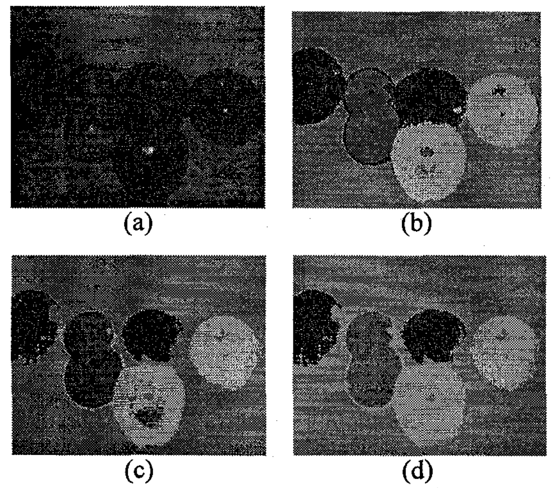

Fig. 4. A fruit image. (a) The original image; (b) the segmentation result using 3-D clustering; (c) the segmentation result using 1-D clustering; (d) the segmentation result using the proposed circular-histogram thresholding.

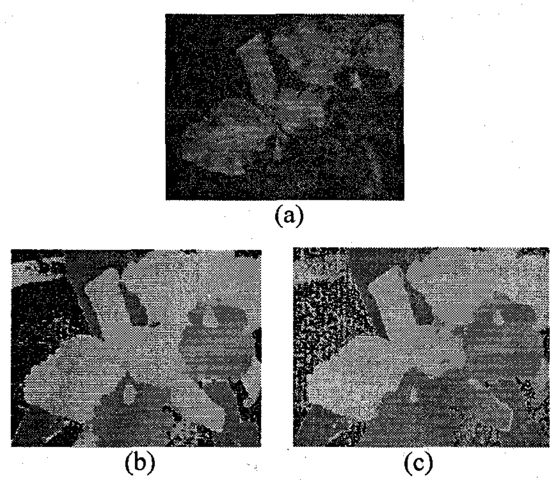

Fig. 5. A flower image. (a) The original image; (b) the thresholded result using the proposed circular-histogram thresholding based on the UCS hue attribute; (c) the thresholded result using the proposed circular-histogram thresholding based on a non-UCS hue attribute.

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