Color Segmentation Using Perceptual Attributes

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Abstract

A general approach for achieving color image segmentation using uniform-chromaticity-scale perceptual color attributes is proposed. At first chromatic and achromatic areas in a perceptual *IHS* color space are defined. Then image is separated into chromatic and achromatic regions according to the region locations in the color space. 1-D histogram thresholding for each color attribute is performed to split the chromatic and achromatic regions, respectively. Finally region growing is used to solve oversegmentation problem. In experiment we demonstrate the power of the proposed approach.

I. Introduction

A fundamental capability of computer vision system forming interpretations in terms of components of image is to segment image into several disjoint regions possessing uniform characteristics. Several researchers have investigated the use of color for segmentation. They realized that color information from natural scenes could greatly simplify the process of segmentation.

A classic histogram thresholding for color segmentation was reported by Ohlander *et al.* [1]. It is a multi-dimensional thresholding scheme, and threshold values were obtained from three different color spaces (*RGB, YIQ* and *HSL*). A similar approach using recursive histogram thresholding technique in the Munsell color space was proposed by Tominaga [2]. By the same way, Ohta *et al.* [3] used various color spaces for color segmentation. A classic clustering technique for color segmentation was reported by Celenk [4]. It detected image clusters in some circular-cylindrical decision elements of the (L^*,a^*,b^*) color space using 1-D histogram. A two-dimensional clustering technique was described by Underwood *et al.* [5]. Which is based on the projections of normalized color space onto two-dimensional planes. An interactive method for three-dimensional clustering in the (X,Y,I) color space was employed by Sarabi *et al.* [6].

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There are two important ideas for color segmentation, which are uniform chromaticity scale (UCS) and human perception. The UCS color space means that the color difference of human perception can be directly expressed by an Euclidean distance in the color space [7]. (L^*,a^*,b^*) and (L^*,u^*,v^*) color spaces are approximately UCS. On the contrary, (R,G,B) and (X,Y,Z) color spaces are non-UCS. Achieving an adequate segmentation result depends on segmentation techniques by detecting similarity among the attributes of image pixels. The UCS is a mathematical system to match sensitivity of human eyes with computer processing. Color has psychological attributes; the perceptual color space is usually described by intensity, hue and saturation (*IHS*). The intensity is a measure of total reflectance in the visible region of spectrum, and it is an achromatic component of color. The hue is the attribute of color perception denoted by red, yellow, green, blue, and so on. Saturation is used to describe how pure a color is or how much white is added to a pure color. Using perceptual color space for color image segmentation has two advantages : (1) specifying and controlling color is more suitable for intuition of human than using the primary colors *RGB*; (2) it can control intensity and chromatic components more easily and independently.

In this paper a general approach for color image segmentation based on the ideas of uniform chromaticity scale and human perception is proposed. The approach can overcome the shade problem to achieve an adequate segmentation which is difficultly accomplished by gray-level information alone.

II. Color Models

In this research we use the approximated UCS color space (L^*,u^*,v^*) to establish the special perceptual color space (I,H,S) for our segmentation approach. The NTSC *RGB* values are transformed into the *XYZ* values of the CIE-(X,Y,Z) color space by using the formulas [8] :

$$\begin{cases} X = 0.607R + 0.174G + 0.201B \\ Y = 0.299R + 0.587G + 0.114B \\ Z = 0.000R + 0.066G + 1.117B \end{cases} . \qquad (1)$$

We calculate the $L^*u^*v^*$ values of the (L^*,u^*,v^*) color space from the XYZ values by using the equations [8] :

$$\begin{cases} L^* = 25\,(100Y/Y_o)^{1/3} - 16 \\ u^* = 13\,L^*(u' - u_o) \\ v^* = 13\,L^*(v' - v_o) \end{cases} \tag{2}$$

with

$$u' = \frac{4X}{X+15Y+3Z} \quad \text{and} \quad v' = \frac{9Y}{X+15Y+3Z},$$

where Y_o, u_o and v_o are the values of the reference white. Decision of reference white mainly depends on characteristics of color display devices and sensitivity of human eyes. From the reference white $(R,G,B) = (1,1,1)$ in the NTSC receiver primary system, we compute the values of Y_o, u_o and v_o to be 1.000, 0.201 and 0.461, respectively. Every color is represented as a point in the (L^*,u^*,v^*) three-dimensional color space, and the color difference of two color points is consistent with the measurement of the Euclidean distance in the space. We calculate IHS values from the $L^*u^*v^*$ values by using the equations :

$$\begin{cases} I = L^* \\ H = arctan\,(\frac{v^*}{u^*}) \\ S = [(u^*)^2 + (v^*)^2]^{1/2} \end{cases} . \tag{3}$$

H is the angle for representing hue gamut; we compute that angle 222^o represents pure red, angle 318^o represents pure green , and angle 80^o represents pure blue. we see that the (I,H,S) model is just the cylindrical coordinates of the (L^*,u^*,v^*) space.

III. Color Difference Measurement

Measure of color difference is an important problem for color analysis. In general, gray-level difference of two gray levels g_1 and g_2 in a monochrome image is calculated directly :

$$\text{gray level difference} = \left| g_1 - g_2 \right| . \tag{4}$$

By the same way, the color difference of two points (R_1,G_1,B_1) and (R_2,G_2,B_2) in the (R,G,B) space can be directly derived from Eq. (4) as

$$(\left|R_1 - R_2\right| + \left|G_1 - G_2\right| + \left|B_1 - B_2\right|)$$

or

$$((R_1 - R_2)^2 + (G_1 - G_2)^2 + (B_1 - B_2)^2)^{1/2} .$$

However, the formulas are not suitable for the measurement in cylindrical coordinates. Here we use another color difference formulas for the UCS (I,H,S) color space to match the color variation of human perception. Assume the coordinates of two color points (I_1,H_1,S_1) and (I_2,H_2,S_2) in the (I,H,S) color space, based on the UCS characteristics, the color difference of these two points is defined :

$$\text{color difference} = ((d_I)^2 + (d_C)^2)^{1/2}, \tag{5}$$

with

$$d_I = \left| I_1 - I_2 \right|$$

and

$$d_C = ((S_1)^2 + (S_2)^2 - 2\,S_1\,S_2\,cos\theta)^{1/2},$$

where

$$\theta = \begin{cases} \left|H_1 - H_2\right| & \text{if } \left|H_1 - H_2\right| < 180^o; \\ 360^o - \left|H_1 - H_2\right| & \text{if } \left|H_1 - H_2\right| > 180^o. \end{cases}$$

The values d_I is the intensity distance between the points, the value d_C is the distance between the projections of the points on a chromatic plane, and the angle θ is an acute angle between H_1 and H_2 angles.

IV. Segmentation method

The UCS (I,H,S) color space has been described. Now the general approach for color image segmentation based on the color space will be given.

A. *Overview of approach*

The procedure of the approach consists of the following steps :

Step1. Convert NTSC-*RGB* values through CIE-(X,Y,Z) and (L^*,u^*,v^*) spaces to IHS values.

Step2. Define the effective ranges of hue and saturation in the (I,H,S) space, and determine chromatic and achromatic regions in the image.

Step3. Use intensity, hue and/or saturation one-dimensional histogram thresholdings to split chromatic and achromatic regions.

Step4. Detect and recover oversegmentation regions using region growing technique.

B. *Define chromatic and achromatic regions*

In IHS color representation, hue has the greatest discrimination power among the three attributes. Moreover, hue can also be exploited for color segmentation under non-uniform illumination such as shade or highlight, because hue is independent on intensity attribute [2]. Although hue is the most useful attribute, there are three problems in using hue attribute for color segmentation : (1) hue is meaningless when the intensity is very low or high; (2) hue is unstable when the saturation is very low; and (3) saturation is meaningless when the intensity is very low or very high.

In order to determine the effective ranges of hue and saturation for color image segmentation, we need to define an achromatic area in the (I,H,S) color space based on the above concepts; and determine which region in image belongs to achromatic area, and which region belongs to chromatic area. From the concepts and characteristics of color display systems, we define the achromatic area in the (I,H,S) color space as follows :

Zone one : (intensity > 95) or (intensity < 25),
Zone two : (81 < intensity < 95) and (saturation < 18),
(61 < intensity < 80) and (saturation < 20),
(51 < intensity < 60) and (saturation < 30),
(41 < intensity < 50) and (saturation < 40),
(25 < intensity < 40) and (saturation < 60),

while intensity is re-scaled from 1 to 100, and saturation is variable with a maximal value of 180. The achromatic area is divided into two zones. The criteria were measured by experimental observation of human eyes. The approximated configuration of chromatic and achromatic areas in the (I,H,S) color space is shown in Fig.1. Some parts of color image will be classed to chromatic region, and the others will be classed to achromatic region according to their pixel locations in the color space.

C. Region splitting using histogram thresholdings

An image has been segmented into achromatic and chromatic regions. Here we will use histogram thresholding technique to further segment the image into a set of uniform regions based on intensity, hue and/or saturation. We have stated that hue is the most useful attribute for color segmentation. Thus we first segment chromatic region using hue histogram thresholding and achromatic region using intensity histogram thresholding. In general, it is sufficient to get a good result. If necessary, we continuously check each chromatic region. If its saturation histogram has obvious variation distribution, we split the region based on the saturation histogram more detailed. In the histogram thresholdings, we use an automatic method based on the shape of histogram to iteratively detect peak areas in the histogram [2]. We choose a significant peak according to its sharpness function, S, defined as :

$$S = Tp \,/\, Wp \,, \tag{6}$$

where Tp indicates the total number of pixels between two valleys (i.e., a peak area), and Wp indicates the width of the peak area. We choose the peak if its S value is greater than the pre-defined criterion. In experiment, the S criterion for hue histogram is taken to be 256 and for intensity histogram is taken to be 1536.

D. Recovery of oversegmentation

Due to the influence of shade or highlight, some regions in images may be split into meaningless subregions called oversegmentation regions in the previous processes. In order to recover the oversegmentation problems, we analyze changes of color clusters caused by illumination variation and propose a method to detect and merge the oversegmentation regions.

Due to partial shade, a uniform-hue region may be separated into several subregions. It means that some subregions may be moved from original location to achromatic area in the color space, because the saturation of the cluster for shading region become low. The subregions can be divided into three types according to the influence of illumination variation :

Type 1 : Subregion has no shade, and possesses original hue and saturation values. It is considered that its location has not changed in the color space.

Type 2 : Subregion has a little influence of shade, and possesses unstable hue and changed saturation. Its location may be moved to the band area between chromatic and achromatic areas in the color space.

Type 3 : Subregion has great influence of shade. It almost lose saturation information, and its hue becomes meaningless. Its location is moved into the achromatic area of the color space.

At first we detect type-2 subregions in the image. An 8×8 mask is evenly divided into sixteen 2×2 sub-masks. If there is at least a chromatic pixel and an achromatic pixel in the 2×2 sub-mask, then we say that the sub-mask has a vote to the dispersion of the mask. If the mask possesses more than seven votes, we take the 8×8 region to be a type-2 subregion. Convoluting the mask throughout the image to find all type-2 subregions. Then we use region growing technique to merge the type-2 subregions to segmented regions or to form some independent regions based on the concept of clustering in the (I,H,S) color space. Taking the center point of a subregion as a seed which is a start point of region growing process in the image. Sequentially merge the pixels adjoined to the seed or the segmented pixels. In each merge step, we map the considered pixels to the (I,H,S) color space to check whether they form a cluster, and re-calculate the center of the cluster. If they do not belong to the same cluster, we will choose next neighbor pixel to process until no connected pixel satisfies the similarity criterion of color.

V. Experimental Results

A complete example from separation of chromatic and achromatic regions to recovery of oversegmentation is shown in Fig.2. In order to distinguish the segmented regions, we give a pseudo-color for each region on the segmented image. Fig.2(a) is a flower image. Fig.2(b) shows the result after separation of chromatic and achromatic regions. Fig.2(c) shows the result processed by hue and intensity histogram thresholdings. We see that the petal has the same hue and two different saturation levels, thus the petal is split into a single region. If we continuously split the chromatic region using saturation attribute, then the result become that shown in Fig.2(d). The petal is split into two parts. One has full saturation, and the other has less saturation. Fig.2(e) shows the result processed after recovery of oversegmentation.

In addition to the example, several experiments have also be performed. All pictures were taken by using a TARGA PLUS image card with 24 bits/pixel; and all images were print-out from an AVIO FR-1000 film recorder.

VI. Conclusions

A general approach for color image segmentation using UCS perceptual attributes was proposed. Several segmentation problems have been solved by the proposed segmentation approach. The influence of illumination variation could be effectively eliminated by the approach. Although good results can be gained by using the proposed segmentation approach, there are still two problems concerning the segmentation results. One is the measurement of achromatic area in the (I,H,S) color space. An accurate measurement of achromatic area is necessary for gaining better results. However, it is difficult to establish, because different color has different correlation in intensity, hue and saturation. Another problem is that the proposed approach overcoming the problem of shade and highlight is limited. That is, if the shade or highlight is too strong on object surface, the parts of object surface which are covered by the shade or highlight will lose all color information, then the subregions can not be merged.

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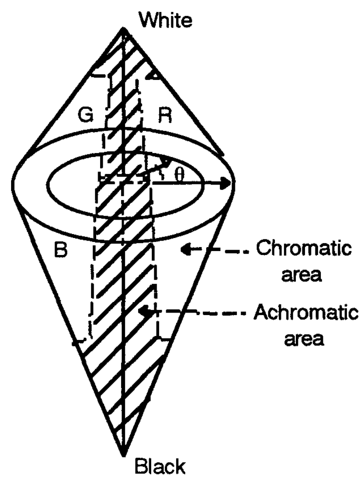

Fig.1. The configuration of chromatic and achromatic areas in the *IHS* space.

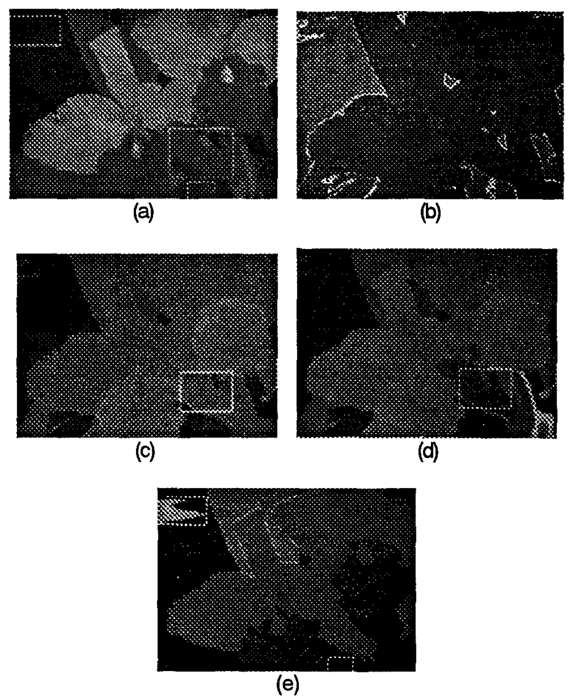

Fig.2. A flower image. (a) the original image. (b) the chromatic and achromatic regions. (c) the result processed by hue and intensity histogram thresholdings. (d) the result processed by intensity, hue and saturation histogram thresholdings. (e) the finally result after recovery of oversegmentation. (All images are true color or pseudo color originally.)