COLOR IMAGE SEGMENTATION USING CONNECTED REGIONS

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Abstract

A color image segmentation algorithm based on region growing is presented. Each region is characterized using two parameters: within region color contrast and between region color contrast. The first parameter is the distance between the two most distant pixels in terms of color. The second parameter is the distance between the candidate pixel and its nearest neighbor in the region. The color similarity measure used is the vector angle, which is invariant to shading. Highlight invariance is accomplished by using a highlight removal transformation, which removes the average pixel intensity from each RGB coordinate. The first calculation is very computationally intensive. To reduce this computational burden, the algorithm keeps track of which pixels already in the region are furthest spatially from the pixel being considered. The assumption would be that the pixels the furthest away would be the ones most different from the pixel being considered. We will present results on artificial and real images to illustrate the effectiveness of the method.

Keywords: color image segmentation, region growing, highlight invariance, shading invariance

1. INTRODUCTION

Humans perceive object surfaces in a scene in spite of shading and highlight effects. This effect is called color constancy - the perception of objects in the real world without illumination effects and has been a major concern in the research community of image science and technology. This paper proposes an algorithm for color image segmentation which is invariant to shading and highlight effects based on the Dichromatic Reflection Model (DRM) [1]. DRM is a useful tool for modeling light reflection and will be used as the theoretical foundation of this paper.

Common approaches for color image segmentation are clustering algorithms such as k-means [2] or Mixture of Principal Components [3], however these algorithms do not take spatial information into account. Furthermore, clustering algorithms require prior information regarding number of clusters, which is a difficult or ambiguous task, requiring the assertion of some criterion on the very nature of the clusters being formed. Some progress has been made on this issue however, much experimentation still needs to be done [5].

An alternative set of algorithms exists which uses color similarity and a region-growing approach to spatial information [7]. Region growing is based on the following principles. The algorithm starts with a seed pixel, examines local pixels around it, determines the most similar one, which is then included in the region if it meets certain criteria. This process is followed until no more pixels can be added. The definition of similarity may be set in any number of different ways.

Region growing algorithms have been used mostly in the analysis of grayscale images [14] however, some significant work has been completed in the color realm by Tremeau et al. [6]. They discuss the segmentation of RGB color regions which are homogeneous in color (i.e., no illumination effects are considered) thus restricting the application domain. They use a set of thresholds when calculating whether a color pixel is part of a region or not, and the Euclidean distance is used as the measure of similarity between two color vectors. In [10], the authors describe a method where pixels are aggregated together when the distances between the candidate pixel and an adjacent pixel belonging to the region, and between the candidate pixel and the region prototype are both less than some experimentally set thresholds. The region prototype is determined by computing the vector mean of the pixels within the region. The similarity is assessed as in [6] using the Euclidean distance on the other hand, the YZ space together with normalized *uv* planes is used (for a total of 5 color planes). However, it is well established that the Euclidean distance poorly models the human perception of color similarity [8].

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Finally, Wesolkowski and Fieguth [13] describe a region growing method for color image segmentation characterized by two parameters. The first is the distance between the region prototype and the candidate pixel. The second is the distance between the candidate pixel and its nearest neighbor in the region. The inner vector product or vector angle is used as the similarity measure, which makes both of these measures shading invariant.

This paper describes a modification to this method where the second parameter keeps track of the distance between the two most dissimilar colors in the region by calculating the maximum distance between the pixels on the *convex cone* (vector angle analogue to the convex hull) of all the pixels in the region. The assumption is that most pixels belonging to the region will be inside the convex cone. This modification is based on the parameterized connected component theory defined for greyscale images [14]. Wang et al. describe a connected component method based on two parameters. The first measure is the gradient between a pixel on the region boundary and the candidate pixel next to it. The second is defined as the maximum distance/gradient between two pixels in the region. If similar reasoning was used to calculate this parameter for color images the complexity would have been $O(n^3)$.

This paper is organized as follows. Highlight and shading invariance methods based on the Dichromatic Reflection Model are introduced in Section 2. In Section 3, the region growing algorithm used for color image segmentation is explained in detail. Section 4 describes the results while Section 5 concludes the paper.

2. COLOR THEORY

The Dichromatic Reflection Model (DRM) [11,12] states that light is reflected in two distinct components: specular reflection and diffuse reflection. This paper will focus on inhomogenous dielectric materials such as plastics. The presentation of the DRM follows closely that given in [5]. Light reflected from an object surface is described as:

$$C^o(\lambda,x)=\alpha(x)S^o(\lambda)E(\lambda)+\beta(x)E(\lambda) \qquad (1)$$

where the first term representing body reflection and the second specular reflection. $E(\lambda)$ is the spectral power distribution of a light source. $S^o(\lambda)$ is the spectral-surface reflectance of object o, while $\alpha(x)$ is the shading factor and $\beta(x)$ is a scalar factor for the specular reflection term. The terms are a function of pixel location x and wavelength λ. Sensor responses can be represented with

$$\begin{aligned}\begin{bmatrix}R\\G\\B\end{bmatrix} &= \alpha(x)\int S^o(\lambda)E(\lambda)\begin{bmatrix}R_R(\lambda)\\R_G(\lambda)\\R_B(\lambda)\end{bmatrix}d\lambda + \\ &\quad \beta(x)\int E(\lambda)\begin{bmatrix}R_R(\lambda)\\R_G(\lambda)\\R_B(\lambda)\end{bmatrix}d\lambda \\ &= \alpha(x)\vec{c}_b+\beta(x)\vec{c}_i\end{aligned} \qquad (3)$$

where $R_i(\lambda)$ (i=R,G,B) are the camera s spectral sensitivity functions in the visible spectrum, $\vec{c}_b$ and $\vec{c}_i$ (normalized to unit vector length) are the body and the illumination color vectors. If the sensor outputs R, G, and B are balanced for a white surface, then the illumination is considered to be white light. This is satisfied as long as the spectral sensitivity functions have the same areas. Otherwise a white balancing procedure needs to be carried out [5,12].

In [5], the authors demonstrate how highlight invariance is obtained by applying the following transformation:

$$\begin{aligned}R' &= R\text{-}AVG\\ G' &= G - AVG\\ B' &= B\text{-}AVG\end{aligned}$$

Since the algorithm described in this paper also uses the vector angle to discriminate between colors, the method is also said to be shading invariant, which has been demonstrated previously [5].

3. CONNECTED REGIONS ALGORITHM

A new parameter-dependent region growing algorithm is proposed in this paper based on the vector angle color similarity measure and the use of the convex cone (based on the vector angle) of pixels in the region, with the goal of a region-based segmentation which is perceptually-based. The algorithm is described as follows:

1. Select seed pixels within the image
2. From each seed pixel grow a region:
    - 2.1. Set the convex cone to be the seed pixel and the next two most similar adjacent pixels
    - 2.2. Determine if the candidate pixel is included within the convex cone and calculate ρ, the maximum distance between pixels on the new convex cone

2.3. Calculate δ, the similarity between the candidate and its nearest neighbor in the region
2.4. Add the pixel to the region if both δ and ρ are less than a set threshold
2.5. Expand the convex cone to include the candidate pixel if it is outside of the convex cone with ρ smaller than a set threshold
2.6. Go to the next pixel to be examined.

This algorithm has a number of advantages with respect to other methods. First, it uses the vector angle, which has been shown to be a shading-invariant color similarity measure [4]. Next, since spatial information is taken into account, regions having a slightly different color, but still spatially distinct, should appear as separate regions given suitable parameters for ρ, the largest angle between pixels on the convex cone.

A significant drawback of this method is the need for seed pixels, which need to be carefully selected. In [10], a complex neural network-based approach is used to determine seed pixels. In [9], authors give an algorithm for selecting seed pixels based on hue values in the HSI space. Other approaches include finding pixels with the greatest intensity globally, pixels with maximum local intensity or using the MPC algorithm. In this paper, seed points are found using the standard second derivative to determine points of local maximum intensity.

Finally, using the convex cone to keep track of the maximum separation between pixels in the region is clearly similar to calculating the distance between candidate pixels and the corresponding region prototype [13]. The latter is an approximation of the former.

4. RESULTS

Results are shown on a real color scene with different illumination intensities (see Figures 1 and 2). The results of the region growing algorithm from [13] are shown in Figures 3 and 4. Preliminary experiments on small images show consistent results with the algorithm presented in [13].

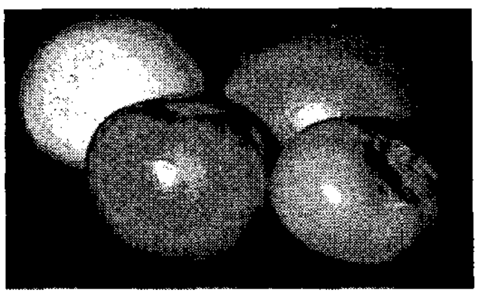

Figure 1: Color scene image with high illumination intensity

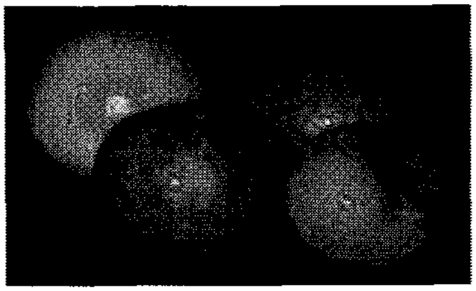

Figure 2: Color scene image with low illumination intensity

Figure 3: Region growing results for Figure 1 [13].

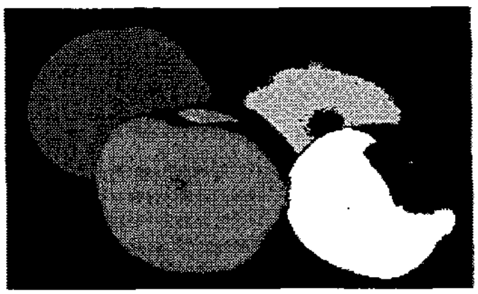

Figure 4: Region growing results for Figure 2 [13].

However, the computation at almost each iteration of the convex cone requires a great deal of computation. Therefore, the region growing algorithm presented in [13] seems a much better choice for addressing this problem. Full results for the connected regions algorithm based on Figures 1 and 2 will be presented at the conference.

The black area represents the lack of regions since no meaningful regions are present there. The results in Figures 3 and 4 clearly show that most of the highlights have been absorbed into their appropriate regions. Some highlights remain due to trade offs in adjusting parameters. A low number of the pixels in Figures 1 2 are fully saturated, and, therefore, in this case, this does not seem to be a significant factor in these results.

5. CONCLUSIONS

A region growing algorithm based on parameter dependent connected components that is invariant to shading and highlights has been presented. The preliminary results obtained with this algorithm and with one developed previously [13] show that a region growing framework is an alternative to global clustering-type algorithms such as MPC. Further work is necessary in setting the parameters appropriately and devising appropriate region merging algorithms to handle pixel variations due to saturated highlights. Finally, the extensive computational burden of this method needs to be examined and ways to reduce it investigated.

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