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Color image segmentation using histogram thresholding – Fuzzy C-means hybrid approach

Khang Siang Tan, Nor Ashidi Mat Isa*

Imaging and Intelligent Systems Research Team (ISRT), School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia

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This paper presents a novel histogram thresholding – fuzzy C-means hybrid (HTFCM) approach that could find different application in pattern recognition as well as in computer vision, particularly in color image segmentation. The proposed approach applies the histogram thresholding technique to obtain all possible uniform regions in the color image. Then, the Fuzzy C-means (FCM) algorithm is utilized to improve the compactness of the clusters forming these uniform regions. Experimental results have demonstrated that the low complexity of the proposed HTFCM approach could obtain better cluster quality and segmentation results than other segmentation approaches that employing ant colony algorithm.

1. Introduction

Color is one of the most significant low-level features that can be used to extract homogeneous regions that are most of the time related to objects or part of objects [1–3]. In a 24-bit true color image, the number of unique colors usually exceeds half of the image size and can reach up to 16 millions. Most of these colors are perceptually close and cannot be differentiated by human eye that can only internally identify a number of 30 colors in cognitive space [4,5]. For all unique colors that perceptually close, they can be combined to form homogeneous regions representing the objects in the image and thus, the image could become more meaningful and easier to be analyzed. In image processing and computer vision, color image segmentation is a central task for image analysis and pattern recognition [6–23] It is a process of partitioning an image into multiple regions that are homogeneous with respect to one or more characteristics.

Although many segmentation techniques have been appeared in scientific literature, they can be divided into image-domain based, physics based and feature-space based techniques [24]. These segmentation techniques have been used extensively but each has its own advantages and limitations. Image-domain based techniques utilize both color features and spatial relationship among color in its homogeneity evaluation to perform segmentation. These techniques produce the regions that have reasonable compactness of regions but facing difficulty in the selection of suitable seed regions. Physics based techniques utilize the physical models of the reflection properties of material to carry out color segmentation but more application specific, as they model the causes that may produce color variation. Feature-based techniques utilize color features as the key and the only criteria to segment image. The segmented regions are usually fragmented since the spatial relationship among color is ignored [25]. But this limitation can be solved by improving the compactness of the regions.

In computer vision and pattern recognition, Fuzzy C-means (FCM) algorithm has been used extensively to improve the compactness of the regions due to its clustering validity and simplicity of implementation. It is a pixels clustering process of dividing pixels into clusters so that pixels in the same cluster are as similar as possible and those in different clusters are as dissimilar as possible. This accords with segmentation application since different regions should be visually as different as possible. However, its implementation often encounters two unavoidable initialization difficulties of deciding the cluster number and obtaining the initial cluster centroids that are properly distributed. These initialization difficulties have their impacts on segmentation quality. While the difficulty of deciding the cluster number could affect the segmented area and region tolerance for feature variance, the difficulty of obtaining the initial cluster centroids could affect the cluster compactness and classification accuracy.

Recently, some feature-based segmentation techniques have employed the concept of ant colony algorithm (ACA) to carry out image segmentation. Due to the intelligent searching ability of the

* Corresponding author. Tel.: +60 45996093; fax: +60 45941023.
E-mail addresses: khangsiang85@hotmail.com (K. Siang Tan), ashidi@eng.usm.my (N.A. Mat Isa).

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ACA, these techniques could achieve further optimization of segmentation results. But they are suffering from low efficiency due to their computational complexity. Apart from obtaining good segmentation result, the improved ant system algorithm (AS) as proposed in [26] could also provide a solution to overcome the FCM's sensitiveness to the initialization condition of cluster centroids and centroid number. However, the AS technique does not seek for very compact clustering result in the feature space. To improve the performance of the AS, the ant colony – Fuzzy C-means hybrid algorithm (AFHA) is introduced [26]. Essentially, the AFHA incorporates the FCM algorithm to the AS in order to improve the compactness of the clustering results in the feature space. However, its efficiency is still low due to computational complexity of the AS. To increase the algorithmic efficiency of the AFHA, the improved ant colony – Fuzzy C-means hybrid algorithm (IAFHA) is introduced [26]. The IAFHA adds an ant sub-sampling based method to modify the AFHA in order to reduce its computational complexity thus has higher efficiency. Although the IAFHA's efficiency has been increased, it still suffers from high computational complexity.

In this paper, we propose a novel segmentation approach called Histogram Thresholding – Fuzzy C-means Hybrid (HTFCM) algorithm. The HTFCM consists of two modules, namely the histogram thresholding module and the FCM module. The histogram thresholding module is used for obtaining the FCM's initialization condition of cluster centroids and centroid number. The implementation of this module does not require high computational complexity comparing to those techniques using ant system. This marked the simplicity of the proposed algorithm.

The rest of the paper is organized as follows: Section 2 presents the histogram thresholding module and the FCM module in detail. Section 3 provides the illustration of the implementation procedure. Section 4 analyzes the result obtained for the proposed approach and at the same time comparing it to other techniques. Finally, Section 5 concludes the work of this paper.

2. Proposed approach

In this paper, we attempt to obtain a solution to overcome the FCM's sensitiveness to the initialization conditions of cluster centroid and centroid number. The histogram thresholding module is introduced to initialize the FCM in view of the drawbacks by taking the global information of the image into consideration. In this module, the global information of the image is used to obtain all possible uniform regions in the image and thus the cluster centroids and centroid number could also be obtained. The FCM module is then used to improve the compactness of the clusters. In this context, the compactness refers to obtaining the optimized label for each cluster centroid from the members of each cluster.

2.1. Histogram thresholding

Global histogram of a digital image is a popular tool for real-time image processing due to its simplicity in implementation. It serves as an important basis of statistical approaches in image processing by producing the global description of the image's information [27]. For color images with RGB representation, the color of a pixel is a mixture of the three primitive colors red, green and blue. Each image pixel can be viewed as three dimensional vector containing three components representing the three colors of an image pixel. Hence, the global histograms representing three primitive components, respectively, could produce the global information about the entire image.

The basic analysis approach of global histogram is that a uniform region tends to form a dominating peak in the corresponding histogram. For a color image, a uniform region could be identified by the dominating peaks in the global histograms. Thus, histogram thresholding is a popular segmentation technique that looks for the peaks and valleys in histogram [28,29]. A typical segmentation approach based on histogram analysis can only be carried out if the dominating peaks in the histogram can be recognized correctly. Several widely used peak-finding algorithms examined the peak's sharpness or area to identify the dominating peaks in the histogram. Although these peak-finding algorithms are useful in histogram analysis, they sometimes do not work well especially if the image contains noise or radical variation [30,31].

In this paper, we propose a novel histogram thresholding technique containing three phases such as the peak finding technique, the region initialization and the merging process. The histogram thresholding technique applies a peak finding technique to identify the dominating peaks in the global histograms. The peak finding algorithm could locate all the dominating peaks in the global histograms correctly and have been proven to be efficient by testing on numerous color images. As a result, the uniform regions in the image could be obtained. Since any uniform region contains 3 components representing the 3 colors of the RGB color image, each component of the uniform region is assigned one value corresponding to the intensity level of one dominating peak in their respective global histograms. Although the uniform regions are successfully obtained, some uniform regions are still perceptually close. Thus, a merging process is applied to merge these regions together.

2.1.1. Peak finding

Let us suppose dealing with color image with RGB representation which each of the primitive color components' intensity is stored in n-bit integer, giving a possible $L=2^n$ intensity levels in the interval $[0, L-1]$. Let $r(i)$, $g(i)$ and $b(i)$ be the red component, the green component and the blue component histograms, respectively. Let x_i, y_i and z_i be the number of pixels associated with ith intensity level in $r(i)$, $g(i)$ and $b(i)$, respectively.

The peak finding algorithm can be described as follows:

i. Represent the red component, green component and blue component histograms by the following equations:

$$r(i)=x_i, \tag{1}$$

$$g(i)=y_i, \tag{2}$$

$$b(i)=z_i, \tag{3}$$

where $0 \le i \le L-1$.

ii. From the original histogram, construct a new histogram curve with the following equation:

$$T_s(i)=\frac{(s(i-2)+s(i-1)+s(i)+s(i+1)+s(i+2))}{5}, \tag{4}$$

where s can be substituted by r, g and b and $2 \le i \le L-3$. $T_r(i)$, $T_g(i)$ and $T_b(i)$ are the new histogram curves constructed from the red component, green component and blue component histograms, respectively.
(Note: Based on analysis done using numerous images, the half window size can be set from 2 to 5 in this study. The half window size that is smaller than 2 could not produce a smooth histogram curve while large half window size could produce different general shape of a smooth histogram curve when comparing it to the original histogram.)