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Stop Rule for Image Hierarchical Segmentation Algorithm

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Abstract

In this paper we consider an important problem of stopping the hierarchical segmentation procedure when the appropriate segmentation is achieved. This problem arises at every segmentation procedure, which uses a searching algorithm for selection of acceptable decision. We propose an algorithm for stopping the hierarchical segmentation procedure. Stop-rule is based on the segmentation homogeneity measure, and uses a ratio of special sum of squares. The first sum equals to summarized variance of pixel intensity relative to the centers of intervals, being determined by thresholds, the second one expresses variance of mean values of the segments relative to the same centers. Examples of segmentation results to demonstrate the features and properties of proposed technique are considered.

1. Introduction

It is well known that image segmentation is an essential component of image analysis system. It is one of the most difficult tasks in image processing, which determines the quality of the final result of analysis. Image segmentation means the partitioning of an image into meaningful regions based on the predetermined criteria of homogeneity and heterogeneity, respectively. The qualitative and quantitative assessment of segmentation results is very important for further image processing as well as for choosing the appropriate approach for a given segmentation task. The accuracy significantly affects the recognition and classification results as well as the derived conclusions. In an ideal case the segments would directly correspond to the real-world objects presented in the image. In practice it is virtually impossible to achieve such a complete segmentation and complete understanding of image contents. As pointed out by a recent paper [1], even the evaluation of human segmentation is a challenging problem. Therefore, creation of enough universal and flexible techniques for arbitrary image segmentation and appropriate measure for segmentation quality is still actual problem.

There are many approaches for segmentation quality determination. We can refer for instance to a survey of evaluation methods for image segmentation [2]. An approach was proposed in [3], which was based on the minimum description length principle, which formulates segmentation as a model selection problem. Given an image, each segmentation is regarded as a model for explaining the image data. The preferred model is one that minimizes the total description length, defined as the sum of the coding length of the model and the coding length of the image using the model. A method and software are implemented in NASA [4], which produces as a result of different hierarchy and resolution levels a set of segmentations. A region-merging procedure is proposed to decrease the segments number. Additionally it allows the most extensive parameter settings of all programs. Due to the multitude of parameter settings there is still a need for optimization regarding the usability.

Earlier a new algorithm of hierarchical segmentation, based on the usage of a homogeneity measure for all resulted segments at every step was proposed by authors [5-6]. A software tool on this basis is created. In [7] the effectiveness of this technique was shown. Moreover, the aforementioned tool was successfully applied to a damaged image restoration especially in the area of cultural heritage.

By authors this approach was called *hierarchical coherent segmentation*. They have pointed out that every element of this method contain some well known algorithms used in many segmentation procedures, but the main advantage of this approach is the unity of segmentation method for an arbitrary image, using some meaningful and interpretable numerical data.

In this paper we consider an important problem of stopping the hierarchical procedure when the appropriate segmentation is achieved. This problem arises at the every segmentation procedure, which uses any searching algorithm for selection of an acceptable decision. We propose an algorithm for stopping the hierarchical segmentation procedure and show the usefulness of that rule.

2. Description of segmentation procedure and stop rule

At first, we consider an image of format Gray Scale (8 bit). So image S of size $N \times M$ has pixels of intensity $s(m,n) \in \{0,1,\dots,255\}$, where $m = 0,1,\dots,M-1$; $n = 0,1,\dots,N-1$. Let $0 < L < 255$ be an integer and the intervals $I_1 = [0,\theta_1]$, $I_2 = [\theta_1+1,\theta_2],\dots, I_{L+1} = [\theta_L+1,255]$ are formed by thresholds $\theta_1,\theta_2,\dots,\theta_L$. Then the connected segments are determined so as each of them contains the pixels from the same intensity interval from the mentioned above. So the segmentation of image S resulted to the set of connected segments $S_1,S_2,\dots,S_K$, which satisfy the following properties

$$S = \bigcup_{i=1}^{K} S_i,\ S_i \cap S_j = 0,\ \text{when } i \neq j,\ i,j = 1,2,\dots,K.$$

Let L be a fixed number of thresholds, and the segments $S_1,S_2,\dots,S_{K_L}$ are obtained by considered algorithm, where K_L is the number of segments. Let n_k^L, $k = 1,2,\dots,K^L$, be the number of pixels, which belong to k-th segment, $\sum_{k=1}^{K^L} n_k^L = M \times N$. Let's denote W_A the intensity of a pixel A, and

$$\overline{W}_k^L = \frac{1}{n_k^L}\sum_{A\in S_k} W_A;\ R_k^L = \sum_{A\in S_k}(W_A - \overline{W}_k^L)^2,\ R^L = \sum_{k=1}^{K^L} R_k^L. \tag{1}$$

We can interpret R_k^L as a measure of homogeneity for k-th segment, and R^L as a measure for segmentation quality as a whole. In [4] this measure is used for stopping the hierarchical segmentation procedure, when R^L is small enough. The disadvantage of this method is that the measure works for zero when L increases to 254.

In this paper we propose a ratio, which has local maximums near a few certain values of L and allows analyzing an image more effectively.

Let pixels of k-th segment belong to an intensity interval I_λ and C_k be the center of interval I_λ.

We consider following three sums of squares.

$$\begin{aligned} S^L &= \sum_{A\in S}(W_A - C_k)^2, \\ R^L &= \sum_{k=1}^{K^L}\sum_{A\in S_k}(W_A - \overline{W}_k^L)^2, \\ Q^l &= \sum_{k=1}^{K_L} n_k^l\left(\overline{W}_k^L - C_k\right)^2, \end{aligned} \tag{2}$$

It can be shown that at $L = 1,2,\dots,254$ we have

$$S^L = R^L + Q^L. \tag{3}$$

Let us introduce the ratio

$$U^L = 1 - \frac{R^L}{S^L} = \frac{Q^L}{S^L}. \tag{4}$$

It is obvious that $0 \le U^L \le 1$. Large values of (4) testify that the pixels of segments have nearly the same variance as the means of segments, i.e. R^L is relatively small. This case can be considered as a good segmentation. So we can use (4) as a measure of segmentation quality. It is clear that the favor values of L must maximize (4), or, at least, lead to enough large values of (4). Moreover, using (4) we can determine maximal value of L to get reasonable segmentation, because at the larger L the segmentation is very detailed, which can't be appropriately interpreted.

Let's note that formulas (2)-(4) remind of the expression of determination coefficient used in the regression analyzes. So we can express (4) by percent and consider it as a portion of concentration of pixels in the traced segments. We also can compare various images by means of (4) on the extent of their segmentability.

3. The results of numerical experiments

Let's consider the results of some computing experiments to demonstrate certain opportunities and efficiency of considered approach.

Figure 1 includes some results of segmentation by algorithm, described above, as well as the corresponding curves of U^L dependence on parameter L. The first column shows the origin images to be segmented; the second one shows the curve of mentioned dependence of U^L on L. The vertical line shows the chosen value of L (stop rule value). The third column shows the same image after segmentation, when the intensities of pixels belonging to k-th segment are changed to the segment mean $\overline{W}_k^L$ at the stop rule value of L. We see that while model images, presented at the first three rows of Table 1 are segmented correctly, the rest are segmented with acceptable visual accordance of the segmentation results to the origin images.

4. Conclusions

In this paper we consider a stop-rule for the hierarchical coherent segmentation procedure, proposed by the authors earlier. Stop-rule is based on the segmentation homogeneity measure, and uses a ratio of special sum squares. The first of them expresses the summarized variance of pixels intensities relative to the centers of intervals, being determined by thresholds, the second one expresses the variance of mean values of the segments relative to the same centers. Examples of segmentation results are considered to demonstrate the features and properties of proposed technique. The proposed ratio of sum squares, perhaps, can be successfully applied as a segmentation quality measure for arbitrary segmentation algorithms.

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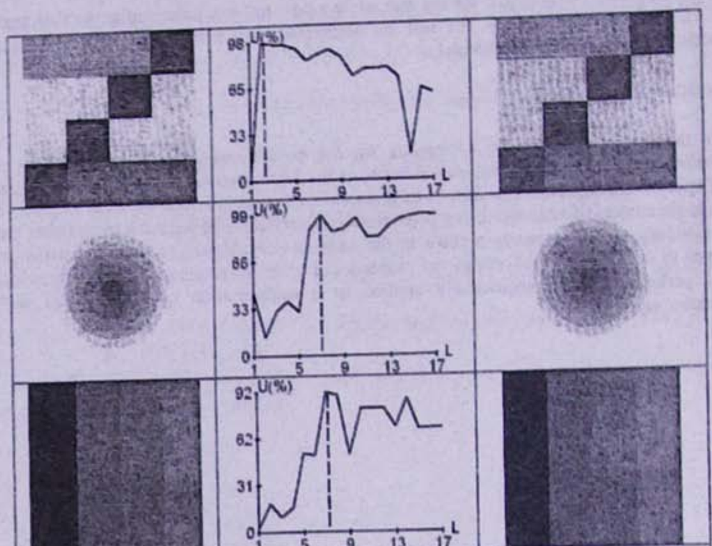

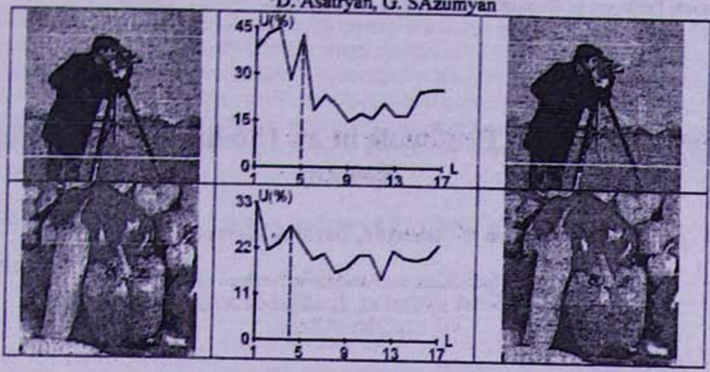

Figure 1. Stopping rule and segmentation results. Left column – original image, middle column – dependence of (4) on L and illustration of stopping rule, right column – segmented image at chosen L.

Կանգառի կանոն՝ պատկերի հիերարխիկ հատվածավորման մեթոդի համար

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Ամփոփում

Նախկինում մշակված՝ պատկերի հիերարխիկ կոհերենտ հատվածավորման մեթոդի համար առաջարկվել է կանգառի կանոն, հենված քառակուսիների գումարների երկու արտահայտությունների հարաբերության վրա: Դրանցից առաջինն արտահայտում է ստացված սեգմենտների փիքսելների պայծառության քառակուսային շեղումը կիրառված շեմերի առաջացրած միջակայքերի կենտրոնների նկատմամբ, իսկ երկրորդը՝ նույն սեգմենտների միջինների քառակուսային շեղումը նույն կենտրոնների նկատմամբ: Նկարագրվել են առաջարկված կանոնի կիրառության արդյունավետությունը ցուցադրող համապատասխան պատկերներ և թվային արդյունքներ: