Evaluation of Colour Image Segmentation Results

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Abstract. The paper presents a new technique of colour image segmentation and its results evaluation. Methods of quantitative evaluation of segmentation results are reviewed. The segmentation technique is based on the concepts of region growing, merging and additionally small regions removal. Results of segmentation are presented using true-colours or pseudo-colours. Three evaluation functions are tested on colour images. The evaluation function *Q(I)* can be used for tuning segmentation parameters.

1 Introduction

Accurate segmentation plays an important role in the image processing systems, because an error in this process will be propagated further. Visual evaluation of segmentation results is very often used to assessment of segmentation process. Unfortunately, different people can evaluate differently. Sometimes the segmentation is indirectly evaluated rely upon results of further processing e.g. recognition rate in object recognition process. Other approaches need specially defined the mislabelling rate [1] or manually segmented image [2]. In literature exist a few methods of quantitative evaluation of image segmentation results [3,4], which for lack of general image segmentation theory are necessary to practical applications. There are briefly presented in Section 2. Section 3 describes a new region-based image segmentation technique. Section 4 shows some results of using evaluation function for tuning presented segmentation technique.

2 Methods of the Automatic Evaluation of Image Segmentation

Liu and Yang [3] empirically defined following evaluation function:

$$\mathbf{F(I)=\frac{1}{1000\,(N\cdot M)}\sqrt{R}\sum_{i=1}^{R}\frac{e_i^2}{\sqrt{A_i}}} \tag{1}$$

where: I is the segmented image, $N{\cdot}M$, size of the image, R, the number of regions in the segmented image, A_i, the area of pixels of the ith region, and e_i the colour error of region i. The colour error in RGB space is calculated as the sum of the Euclidean distances between colour components of pixels of region and components of average colour, which is an attribute of this region in the segmented image. The colour errors in different color space are not comparable and therefore are transformed back to the RGB space.

First term of equation (1) is a normalization factor, the second term penalizes results with too many regions (oversegmentation), the third term penalizes results with non-homogeneous regions. Last term is scaled by the area factor because the colour error is higher for large regions. The idea of using this kind of function can be formulate as: the smaller the value of *F(I)*, the better is the segmentation result. More information about inspiration in building of this function is in [3]. Function *F(I)* does not require any parameters or thresholds and conforms to the visual judgement.

Borsotti et al. [4] have identified limitations of this evaluation function. In the case of many small regions in the segmented image (oversegmentation), the number of regions is large but the colour error of each region may be equal to zero and *F(I)* will be zero too, which means wrongly that segmentation results are very good. The best example of this situation is an image before segmentation: each pixel is one region. Therefore Borsotti et al. modificated the second term in function *F(I)*:

$$\mathbf{F'(I) = \frac{1}{10000\,(N \cdot M)} \sqrt{\sum_{A=1}^{Max} [R(A)]^{1+1/A}} \cdot \sum_{i=1}^{R} \frac{e_i^2}{\sqrt{A_i}}} \qquad \mathbf{(2)}$$

where: *R(A)* is the number of regions with area equal to *A*, and *Max* the area of the largest region in the segmented image. If the number of small regions is growing then thanks to the exponent *(1+1/A)* the value of *F'* increases too. But the function *F'*, like *F* is equal to zero in the case of non-segmented image.

Therefore function *F'* was once again modificated so, the last term penalizes simultaneously regions with big colour error and small regions.

$$\mathbf{Q(I) = \frac{1}{1000\,(N \cdot M)} \sqrt{R} \sum_{i=1}^{R} \left[\frac{e_i^2}{1 + \log A_i} + \left(\frac{R(A_i)}{A_i} \right)^2 \right]} \qquad \mathbf{(3)}$$

where: $R(A_i)$ is the number of regions having an area equal to A_i. Test images were segmented by six clustering methods. More detailed information about both modificated functions is presented in [4].

In the paper [5] Climent et al. incorporated function *Q(I)* into their segmentation algorithm based on graph minimisation i.e. they used the evaluation function not for evaluating, but for segmenting. This algorithm, that does not require tuning parameters, find the segmented image adequate to minimal value of *Q*. Authors shown by using typical test images that their segmentation algorithm generates segmented images, which have a considerably smaller value of function *Q* than other algorithms used in [4].

3 Region-based Segmentation Technique

In paper [6] was proposed the method of region-based image segmentation that does not use special regions or pixels (seeds) to start the segmentation process. At the beginning of the algorithm each pixel has its own label (one-pixel regions). The concept of 4-connectedness was used for its computational simplicity. For region growing process was used the centroid linkage strategy. This strategy includes a pixel in the region if it is 4-connected to this region and has colour value in the specified range from the mean colour of an already constructed region. After inclusion of pixel the region's the mean colour is updated. For this updating recurrent formulae are used.

First a simple raster scan of the colour pixels was employed: from left to right and from top to bottom. Next pass, in this two-pass method, started from the right bottom corner of image. This pass permited additional merging of adjacent regions, which obtained during first pass the colour features satisfying the homogeneity criterion. During this merging process each region with smaller number of pixels was merged into a region with larger area if criterion was fulfiled. After merging a new mean colour of region was calculated and labels of pixels of attached region were modified. The segmentation results were strongly determined by a tuning parameter: threshold *d*, which limits the value of homogeneity criterion e.g. in the case of RGB colour space:

$$\sqrt{(\mathbf{R}-\overline{\mathbf{R}})^2+(\mathbf{G}-\overline{\mathbf{G}})^2+(\mathbf{B}-\overline{\mathbf{B}})^2} \;\leq\; \mathbf{d} \qquad (4)$$

Effective implementation of this segmentation algorithm requires storing for each region such data as: mean colour of region, region size and list of region pixels, in computer memory. Using flexible data structures known as linked lists [7] is very helpful in merging process. The segmented image can be further postprocessed by removal of small regions that are usually not significant in further stages of processing [8]. Small regions very often occur near edges of objects. Its colours are different from the colour of the object and from the colour of the background. Postprocessing needs additional third pass of image from the top left corner to the bottom right corner. If the pixel is within the region, which is smaller than a certain number of pixels, then is reading the list of region pixels. For each pixel from this list the four- neighbourhood is checked for seeking neighbour regions. The difference in colours between small region and each neighbour region is calculated. In other words, small region is merged to the neighbour region, which is nearest in the sense of colour distance. The pre-selected size of small region *A* plays a role of next tuning parameter. Fig. 1 presents the results of segmentation on test image Peppers.

In the case of very noisy images different filters can be applied as pre-processing tools for colour image segmentation. In paper [9] the performance of the new colour image filter was visually evaluated and the number of regions served as a criterion of evaluation of image segmentation. After ending segmentation process the results can be presented as a true-colour image or a pseudo-colour image. In the first case the algorithm "knows" the mean colour for each segmented region. If the image is segmented in other than RGB colour space, mean colour should be transformed back to the RGB components. In the second case where each region should be randomly coloured, we use a random colour generator. In many cases the pseudo-coloured segmented image makes the oversegmentation better visible than the true-coloured segmented image. Fig.2 is a good example of the above opinion.

4 Use of Evaluation Functions for Tuning Segmentation

Experimental investigations of presented algorithm were performed using *F, F′* and *Q* evaluation functions. Fig.3 shows relations between values of evaluation functions and tuning parameters *d* and *A* for the image Peppers. The homogeneity criterion was established in RGB colour space. First we analyzed two-pass segmentation without process of small regions removal. If the parameter *d* tends to zero, then values of functions *F* and *F'* tend also to zero, whereas the number of regions *R* and function *Q* are growing (Fig.3a). The function *Q* obtains the minimal values for *d* between 25 and 40 e.g. *d*=29, *Q*=2902, *R*=5504. This high value of *Q* function we can decrease through removal regions smaller than *A*. In this case a colour error will increase, but the number of segmented regions will decrease more quickly. For *A*=150 pixels we receive following values: *Q*=645, *R*=228 regions. Further increasing the parameter *A* do not change the function *Q* (Fig.3b).

References

1 Gauch, J.M.: Segmentation and Edge Detection. In: The Colour Image Processing Handbook, Sangwine, S.J. and Horne, R.E.N., /Eds./, Chapman and Hall, London (1998) 163-187

2 Wesolkowski, S., Dony, R.D.: A New Method for Quantitative Image Segmentation Evaluation. Proc. of 1st International Conference on Color in Graphics and Image Processing, Saint-Etienne (2000) 186-190

3 Liu, J., Yang, Y.-H.: Multiresolution Color Image Segmentation. IEEE Trans. on PAMI, 16(7), (1994) 689-700

4 Borsotti, M., Campadelli, P., Schettini, R.: Quantitative Evaluation of Color Image Segmentation Results. Patt. Rec. Lett., vol.19, (1998) 741-747

5 Climent J., Grau A., Verges J., Sanfeliu A.: Image Segmentation Based on Graph Minimisation, Revista Electronica de Vision por Computador, no.4, (2000)

6 Palus, H., Bereska, D.: Region-based Colour Image Segmentation. Proc. of 5th Workshop “Farbbildverarbeitung”, Ilmenau (1999) 67-74

7 Stephens, R.: Ready-to-Run Delphi 3.0 Algorithms. Wiley, New York (1998)

8 Sonka, M., Hlavac, V., Boyle R.: Image Processing, Analysis, and Machine Vision, 2nd ed. PWS Publishing, Pacific Grove (1998)

9 Smołka, B., Palus H., Bereska D.: Application of the Self-Avoiding Random Walk Noise Reduction Algorithm in the Colour Image Segmentation. Proc. of 6th Workshop “Farbbildverarbeitung”, Berlin (2000) 21-26