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A simulated annealing-based optimal threshold determining method in edge-based segmentation of grayscale images

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ABSTRACT

Image segmentation is a significant low-level method of the image processing area. As the matter of the fact that there is no selected certainty in interpreting the computer vision problems, there are many likely solutions. Some morphological methods used in image segmentation cause over-segmentation problems. Region merging, the usage of markers and the usage of multi-scale are the solutions for the over-segmentation problems found in the literature. However, these approaches give rise to under-segmentation problem. Simulated annealing (SA) is an optimization technique for soft computing. In our study, the problem of image segmentation is treated as a p-median (i.e., combinatorial optimization) problem. Therefore, the SA is used to solve p-median problem as a probabilistic metaheuristic. In the optimization method that is introduced in this paper, optimal threshold has been obtained for bi-level segmentation of grayscale images using our entropy-based simulated annealing (ESA) method. In addition, this threshold is used in determining optimal contour for edge-based image segmentation of grayscale images. Compared to the available methods (i.e., Otsu, only-entropy and Snake method) in the literature, our ESA method is more feasible in terms of performance measurements, threshold values and coverage area ratio of the region of interest (ROI).

1. Introduction

Image segmentation is one of the main problems in computer vision and video applications. It is used locally or globally to partition an image as bi-level or higher level into different regions belonging to the image. In subjects, such as Image content analysis and feature-extraction, many segmentation methods are used. Comparison of these methods is only possible by practicing them independent of the application and by having a scientific basis [1,2].

There are a lot of methods in the literature dedicated to image segmentation. Zhang et al. [2] classified these methods as being subjective and objective. The most common method for evaluating the efficiency of a segmentation method is subjective evaluation. In subjective evaluation, an expert can discern visually the results produced by different image segmentation algorithms by basing them on self-experiences. This method is quite tedious and it is used on the sets, which is limited to some images determined beforehand. Objective evaluation can be considered in two different groups: system level evaluation and direct evaluation. System level evaluation is indirect. Direct objective evaluation can be considered in two different ways that are analytical methods and empirical methods. Analytical methods are only applicable for evaluating algorithmic or implementation properties of segmentation algorithms. Empirical methods are considered as supervised and unsupervised evaluation. The reader may refer to Zhang et al. [2] study for detailed coverage of evaluation methods.

In our study, we developed an entropy-based simulated annealing (ESA) method for the image segmentation of grayscale magnetic resonance imaging (MRI). In the first part of our study, we provide an unsupervised evaluation method to determine the optimal threshold for bi-level segmentation of a grayscale image. This evaluation method is based on entropy values and the use of simulated annealing (SA) as the optimization method [3–5]. In the segmentation process, the previously obtained optimal threshold is used to segment grayscale MRI images. In the second part of our study, optimal contour detection is provided in order to make appropriate edge-based segmentation by optimal threshold for grayscale MRI images.

Threshold and contour optimization problems have been considered as p-median problem, which is an example of facility layout problem. This problem is one of the basic models in discrete location theory of Operational Research (OR) area. It is classified as NP-hard problem, thus heuristic methods are frequently used to

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solve it [6–8]. This problem is analyzed using the method of SA in this study. The contour's optimization, which is done as a modification of ESA method, is also provided. The performance results of the unsupervised contour optimization method developed by our group are compared with the performance results of Snake method – Active Contour Model (ACM) – which is one of the contour deformation methods [9,10]. The evaluation of performance is based on contours, regions resemblance and performance metrics. These metrics are adapted from information retrieval research area.

Researchers have worked on segmentation of grayscale image in previous studies; however they have studied only on the methods, which are based on either only-entropy [11] or Otsu's method [12]. They have not considered the advantages of ESA. Some SA-based studies involves only p-median problem and its SA solution, nevertheless their solution is not used to segment an image [13]. In some studies for image segmentation, SA is used to improve performance of genetic algorithm (GA), Snake or other methods [14–16].

The region of interest (ROI) of MRI images is important for medical diagnosis. Our testing images are brain and heart (i.e., cardiac) MRI images. The segmentation in ROIs of these images is determined by an expert and is referred to as "*gold standard*" (GS) or, equivalently, "*ground truth*" (GT) references. Therefore, we provide in our study an objective evaluation of performance for our ESA method and a performance comparison of edge-based segmentation results of our ESA method with Snake method's results. The reader should note that the performance evaluation and image segmentation evaluation are different issues. In our study, unsupervised segmentation evaluation method is used to segment grayscale MRI images. Consequently, the performance comparison and evaluation are made for images of obtained results by using image segmentation.

The first main contribution of this study is a novel image segmentation approach based on image entropy-based SA (namely, ESA) method, which provides an optimal solution for pixel-based bi-level segmentation. The problem of image segmentation is treated as a combinatorial optimization problem. In the literature, there are SA approaches for p-median problem solution, but they do not consider the p-median problem as optimal threshold and/or contour determining problem of image segmentation (e.g., Al-khedhairi [13], and Chiyoshi and Galvao [8] study). The second main contribution of this study is a dual one. At an optimal threshold determining level, we developed a different ESA solution for p-median, which has been considered as optimal threshold determining problem of grayscale MRI images. This solution is different from other optimal threshold determining studies (e.g., Fengjie et al. [14], and Luo et al. [15] study). The solution is carried out using *ESA-threshold* algorithm. The results of bi-level thresholding of ESA method are compared with only-entropy method [11] and Otsu's method [12]. At an optimal contour detection level, we developed a solution similar to the first ESA solution for p-median problem, which has been considered as optimal contour of ROI of grayscale MRI images. Our solution is different from other edge-based segmentation studies (e.g., Tang et al. [16] study), as well. In addition, the solution is carried out using *ESA-contour* algorithm.

This paper is organized as follows. Section 2 describes the related works on grayscale image segmentation and some methods for segmentation previously published in the literature. Section 3 provides the details of the p-median problem, and its SA solution. This solution is based on the ESA method developed by our group. In addition, this method is used for bi-level and edge-based image segmentation, as well. The ESA method is implemented in two complementary algorithms, which are called *ESA-threshold* and *ESA-contour*, respectively. The details of these algorithms are given in Section 3, as well. Section 4 provides the experimental results via thresholded MRI images. Section 5 describes the common performance measures (i.e., metrics) and gives place to the comparison of our ESA method with Snake method for edge-based image segmentation. Moreover, evaluation of performance of our ESA method is given in Section 5, as well. Section 6 concludes the paper.

2. Related work

The image that is segmented in the supervised evaluation – one of the empirical methods – is compared with preprocessed or manually segmented image. These types of methods are known as relative evaluation methods [2,17–19] and empirical discrepancy methods [2,20], respectively. These methods are assessed by comparing a segmented image with a reference image known as "*gold standard*" or "*ground truth*" [2,21].

The degree of similarity between expert-segmented and machine-segmented image determines the quality of the segmented image. There are many examples of such opposition-methods, which are used in evaluation of edge-based image segmentation [2,22–24]. Supervised evaluation with usage of markers results morphology-based segmentation and it causes problems many times. These problems are known as "*over-segmentation*" or "*under-segmentation*". Interactive watershed segmentation can be given as an example of such kind of supervisor contributions.

For unsupervised evaluation methods, a segmented image is evaluated in a way in which a reference image is not needed. These methods are also called stand-alone evaluation methods or, equivalently, empirical goodness methods [2,20,25,26]. The image segmentation in these methods are taken in the evaluation process by considering a way in which how well the image is suited to some characteristics designated by an expert is determined. Due to this, these methods are reasonably quantitative, objective and advantageous. Otsu's study known as bi-level thresholding (1979) or binarization can be given as example to these methods [2,12]. Although unsupervised evaluation contains many advantages; full automatic methods are, in any case, exposed to – as it is stated above – over-segmentation and other segmentation problems.

In this section, determination of threshold is discussed, which is the basis of thresholding, ACM, and SA methods in our study. According to the Chen and Li's study [27], the process of separation of an image's background and foreground is a significant preprocessing stage in analyzing image. In this way, useful knowledge for higher level image processing is obtained. Binarization or thresholding are the methods, which have the most common usage area and they try, at first, to determine a gray threshold for some objective criteria; then they try to assign each pixel in any one of the classes as foreground or background [27]. The situation observed at this assignment is if gray value is higher or lower than the determined threshold and the pixel is assigned to a class. In bi-level segmentation, background is distinguished as black, foreground as white class [27]. Document image analysis [27,28], map processing [27,29] and determining the quality of materials [27,30] can be given as example to the usage area of this method. Sezgin and Sankur [31] have analyzed by comparing different 40 thresholding algorithms and they have evaluated their performance. According to this study, these methods are divided in to six different classes. These are histogram-based methods, clustering-based methods, entropy-based methods, object attribute-based methods, spatial methods and local methods which take each pixel's characteristic as basis [27,31].

As it is explained in the study of Chen and Li [27], optimal segmentation thresholding algorithm is determined according to their own independent criteria among these classes. Otsu's method [12] is a thresholding method based on linear discrimination criterion and Kwon's method [31] is based on clustering method. Slightly