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A fast region segmentation algorithm on compressed gray images using Non-symmetry and Anti-packing Model and Extended Shading representation ☆,☆☆

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ABSTRACT

Image segmentation is one of the fundamental steps in image analysis for object identification. The main goal of image segmentation is to recognize homogeneous regions within an image as distinct and belonging to different objects. Inspired by the idea of the packing problem, in this paper, we propose a fast $O(N\alpha(N))$-time algorithm for image segmentation by using Non-symmetry and Anti-packing Model and Extended Shading representation, which was called the NAMES-based algorithm, where N is the number of homogenous blocks and $\alpha(N)$ is the inverse of the Ackerman's function and it is a very slowly growing function. We first put forward four extended Lemmas and two extended Theorems. Then, we present a new scanning method used to process each NAMES block. Finally, we propose a novel NAMES-based data structure used to merge two regions. With the same experimental conditions and the same time complexity, our proposed NAMES-based algorithm, which extends the popular hierarchical representation model to a new non-hierarchical representation model, has about 86.75% and 89.47% average execution time improvement ratio when compared to the Binary Partition Tree (BPT)-based algorithm and the Quadtree Shading (QS)-based algorithm which has about 55.4% execution time improvement ratio when the QS-based algorithm itself is compared to the previous fastest region segmentation algorithm by Fiorio and Gustedt whose $O(N^2)$-time algorithm is run on the original $N \times N$ gray image. Further, the NAMES can improve the memory-saving by 28.85% (5.04%) and simultaneously reduce the number of the homogeneous blocks by 49.05% (36.04%) more than the QS (the BPT) whereas maintaining the satisfactory image quality. Therefore, by comparing our NAMES-based algorithm with the QS-based algorithm and the BPT-based algorithm, the experimental results presented in this paper show that the former has not only higher compression ratio and less number of homogenous blocks than the latter whereas maintaining the satisfactory image quality, but also can significantly improve the execution speed for image segmentation, and therefore it is a much more effective algorithm for image segmentation.

1. Introduction

An efficient representation method can not only save the storage space of images, but also can reduce the time required for some image manipulations [1–3]. For example, Hosny [1] presented an image representation method by using orthogonal Gegenbauer function. Also, he proposed a novel method for accurate and fast computation of orthogonal Gegenbauer moments. Zheng and Sarem [2] proposed a binary image representation algorithm by using the Non-symmetry and Anti-packing Model and the Coordinate Encoding Procedure (NAMCEP). As an application of the NAMCEP representation, they also presented a fast NAMCEP-based algorithm for area calculating. Liu et al. [3] proposed an unsupervised image segmentation approach aimed at salient object

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extraction based on the analysis of the Binary Partition Tree (BPT) which was a hierarchical representation method. In fact, the hierarchical method is an important structural representation method [4–6]. Many efficient algorithms on these Spatial Data Structures (SDS) have been developed [7–15]. In the 1970's, Klinger first presented a quadtree representation method which was based on the pointers for binary images [16]. To further reduce the storage, Gargantini removed the pointers in a Linear QuadTree (LQT) representation method [17]. Later, Chen and Zou [18] proposed a new method of representing a binary image. Their method, called Linear Binary Tree (LBT), was more effective than the LQT method. Up to date, the LQT and the LBT are still two of the most popular hierarchical representation methods which have been widely applied in many fields [19–21]. In the case of compressing binary images, the compression standard, e.g., Joint Bi-level Image experts Group (JBIG) [22], always has better compression performance when compared to any existing SDS for representing binary images. Based on the B-Tree Triangular Coding (BTTC) method, Distasi et al. [23] proposed the first Spatial Data Structure (SDS) for representing gray images. The experimental studies indicated that the BTTC could produce images of satisfactory quality from a subjective and objective point of view, and that one advantage of BTTC over JPEG was that it had shorter execution time [23]. The BTTC-based SDS is really a pioneer work to extend the SDS design from binary images to gray images. Later, a new S-Tree Coding (STC) representation using the S-tree data structure and the Gouraud shading approach for gray image representation was proposed in [24]. Lately, a novel hybrid gray image representation using Spatial- and DCT-based (which was called SDCT) approach was presented in [25]. Inspired by the concept of the packing problem, Chen et al. [26] presented a novel Non-symmetry and Anti-packing Model (NAM) for image representation in order to represent the image pattern more effectively. The reason why the Non-symmetry was put forward was that the Non-symmetry has a capability of representing a packed pattern with the least number of sub-patterns from the point of view of the anti-packing problem, which means that the total data amount of the NAM is the least. Therefore, the NAM representation has the capability of making a pattern achieve the best representation efficiency which cannot be achieved by the traditional SDS representation methods. Later, Zheng et al. [27] extended the SDS design which was based on overlapping representation from binary images to gray images and put forward a novel gray image representation by using the Overlapping Rectangular Non-symmetry and Anti-packing Model (ORNAM) and the extended Gouraud shading approach. The NAM representation method can not only save the storage space of images, but also it can reduce the time required for some image manipulations. For example, Zheng and Sarem [28] proposed a fast algorithm for computing the lower order moments by using the non-overlapping rectangular NAM and Extended Shading representation (NAMES).

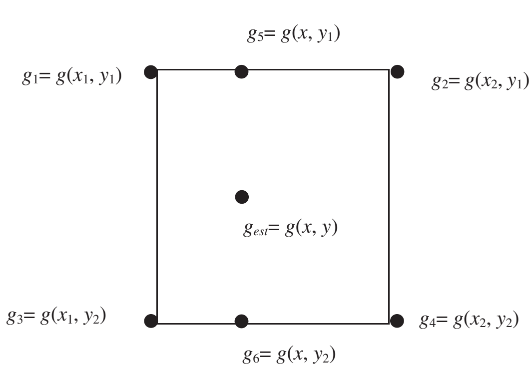

Fig. 1. The sketch of a NAMES block *B*.

Image segmentation, as an important image manipulation, is one of the primary steps in image analysis for object identification. The main goal of image segmentation is to recognize homogeneous regions within an image as distinct and belonging to different objects. The segmentation process can be based on finding the maximum homogeneity in grey levels within the regions identified. Image segmentation has been widely investigated in over fifty decades [29–41]. Panda and Rosenfeld [29] treated image segmentation as a pixel classification problem and put forward an image segmentation method by measuring a set of features at each point and defining a decision surface in the feature space. Sklansky [30] presented an overview of present computer techniques for partitioning continuous-tone images into meaningful segments and characterizing these segments by sets of "features". Shridhar et al. [31] described in details their algorithms for implementing different segmentation strategies. Casey and Lecolinet [32] provided a survey of methods and strategies in character segmentation. Gao et al. [33] presented an image-segmentation system based on some well-known strategies. By assuming that the intensity non-uniformity was smooth in the imaged objects, a novel algorithm that exploited the coherence in the intensity profile for objects segmentation was proposed in [34]. Noble and Boukerroui [35] reviewed ultrasound segmentation methods, in a broad sense, focusing on techniques developed for medical B-mode ultrasound images. Werghi [36] presented a literature survey of the research work on the human body scanner (HBS) data segmentation and modeling aiming at overcoming these challenges, and discussed and evaluated different approaches with respect to several requirements. Nguyen et al. [37] proposed an extension of the standard Gaussian mixture modeling (GMM) for image segmentation, which utilized a novel approach to incorporate the spatial relationships between neighboring pixels into the standard GMM. Katouzian et al. [38] reviewed recently developed image processing methods for the detection of media-adventitia and luminal borders in IVUS images acquired with different transducers and operating at frequencies ranging from 20 to 45 MHz. Cho et al. [39] proposed a new approach to mean-shift-based image segmentation that uses a non-iterative process to determine the maximum of the underlying density. To enhance the robustness against noise, Yang et al. [40] embedded a Markov random field (MRF) energy function to the conventional level set energy function and presented a fast and robust level set method for image segmentation. Wang et al. [41] proposed a novel sparse global/local affinity graph over super-pixels of an input image to capture both short- and long-range grouping cues, and thereby enabling perceptual grouping laws, including proximity, similarity, and continuity, and to enter in action through a suitable graph-cut algorithm. Recently, Udupa et al. [42] classified the image segmentation methods developed up to date into three groups: (a) purely image-based, or PI approaches, wherein the segmentation decisions are made based entirely on the information derived from the given image; (b) object model-based, or OM approaches, wherein known object shape and image appearance information over a population are first codified in a model and then utilized on a given image to bring constraints into the segmentation process; and (c) hybrid approaches, wherein the delineation strengths of the PI methods are combined synergistically with the global object recognition capabilities of the OM strategies.

However, although there are many image segmentation methods over the fifty years and each of the previous three groups is still currently very actively investigated, few of them take the image segmentation into consideration from the point of view of the anti-packing problem. In this paper, inspired by the idea of the packing problem, we investigate a fast region segmentation algorithm on compressed gray images using Non-symmetry and Anti-packing Model and Extended Shading representation.