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Tile-Based Framework with Stability Margin for a Region-Merging Segmentation

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Abstract: Processing of real world remote sensing images on resource-constrained devices is a challenging task because of the large size of these data sets, particularly for very high resolution imagery. For applications such as environmental monitoring or natural resources management, complex algorithms have to be used to extract information from the images. Segmentation algorithms comprise an essential step for the extraction of objects of interest in a large scene. To overcome the memory issue, large images are usually divided into smaller image tiles, which are processed independently. Region-merging segmentation algorithms do not cope well with image tiling since artifacts are present on the tile edges in the final result due to the incoherencies of the regions across the tiles. We propose the concept of the stability margin for a tile for region-merging segmentation algorithms to segment large images. It allows ensuring identical results, with respect to segmentation of the whole image at once.

Keywords: Image processing, image segmentation, image tiling, stability margin, region merging, scalability.

I. INTRODUCTION

Remote Sensing is an important source of data, spatial programs, such as Landsat, that collected more than 4 million images of the Earth's surface over 40 years, are important sources to understand the dynamic of land (Bolch et al., 2010). However, the development of methods to process and analyze this data, is a challenging issue because of the limitation of memory available on computers. Segmentation algorithms constitute an essential step for the extraction of objects of interest in a large scene. To overcome the memory issue, large images are usually divided into smaller image tiles, which are processed independently. For traditional pixelwise or with fixed-size regular neighborhood image processing algorithms, image tiling is straightforward to apply without introducing artifacts in the results. However, those algorithms consider only spectral information from the pixels since a pixel does not have morphological information. That is why new trends known as object-based image analysis (OBIA) [2], object-based image classification [3], spatial and geospatial analysis [7], have recently become apparent using segmentation techniques to extract objects of interest in the scene. However, image tiling does not cope well with region-merging segmentation algorithms. Because image tiling has an impact on the final result. The consequence of image tiling is that artifacts are present on the tile borders as well as segments located on the tile edges are forced to have their contours along the tile edges. There are number of solutions to remove artifacts on the tile edges but we do not relay on the result. In this paper, we use the concept of stability margin [1] to a tile for region merging algorithm to obtain a equivalence of the result to those obtained if the whole image has been segmented at once.

II. REGION MERGING SEGMENTATION ALGORITHM

To obtain a partition of the image, region-based segmentation algorithms [8], [9] do not handle pixels but segments, which are sets of connected pixels. The pixels that belong to the same segment exhibit common properties according to a homogeneity criterion. These algorithms very well suited for object-based image analysis (OBIA) [2].

A. *Homogeneity Criteria for Region-Merging Segmentation:*

The homogeneity criterion can be based on statistical measures [10], spectral information [11], or topological attributes [5].

1) *Spectral information:* The region-growing algorithms, based only on spectral information are the Euclidean distance between spectral vector values [11]. $\mathfrak{R}$ is used to denote the set of regions of the image, and $R \in \mathfrak{R}$ is an element of this set. Let M_i be the mean value vector of the region R_i. Let $D(R_i, R_k) = \parallel M_i - M_k \parallel$ be the Euclidean distance between their spectral mean values of the regions R_i and R_k , and let $N(R)$ be the set of neighboring regions of R. The region R_k is the most similar neighboring region of R_i, if $D(R_i, R_k) \leq D(R_i, R_l)$ for every $R_l \epsilon N(R)$. A threshold T determines the maximum value of the distance to merge the segments.

2) *Spectral and spatial information:* A region-merging algorithm based on spectral and spatial information called the Baatz & Schäpe criterion [5]. Each segment R_i is described by spectral and spatial attributes. The cost of fusion between two adjacent segments R_i and R_j is denoted by $h_{i,j}$ and represents the increase in heterogeneity. Both segments R_i and R_j are merged if $h_{i,j} < s^2$, where s is a scale parameter. $R_{i,j}$ denotes the resulting segment from the fusion of R_i and R_j.

The spectral increase of heterogeneity based on the standard deviation of R_i and R_j is

$$h_{spec_{i,j}} = (a_i + a_j) \cdot \sigma_{i,j} - (a_i \cdot \sigma_i + a_j \cdot \sigma_j) \qquad (1)$$

where $\sigma_{i,j}$ is the standard deviation vector of the pixels contained in $R_{i,j}$.

The total spatial increase of heterogeneity is

$$h_{shape_{i,j}} = \omega_{cpt} \cdot h_{compact_{i,j}} + (1 - \omega_{cpt}) \cdot h_{smooth_{i,j}} \qquad (2)$$

where w_{cpt} ranges from 0 to 1, indicating the degree of compactness relative to the degree of smoothness. Finally, the global increase of heterogeneity when merging these two segments is

$$h_{i,j} = \omega_{spec} \cdot h_{spec_{i,j}} + (1 - \omega_{spec}) \cdot h_{shape_{i,j}} \qquad (3)$$

where ω_{spec} ranges from 0 to 1, indicating the weight of the spectral component relative to the spatial component.

III. PROPOSED SOLUTION

A. Concept of Stability Margin

1) *Definition of Stability Margin:* The goal of this work is to ensure the equivalence of the result when applying segmentation with and without tiling. The experimental way to prove this equivalence is to use the Hoover metrics [6] and check that *RC* = 1. The first result is obtained from the segmentation of the whole image at once. This result represents the reference segmentation and is denoted by *GT*.

For the second segmentation, the image is first divided into rectangular tiles. Each tile is segmented independently, and the result is obtained from the mosaicking of the results of each tile. This result represents the tiled segmentation and is denoted by *TS*. Homogeneity criteria are used for dividing the image into rectangular tiles.

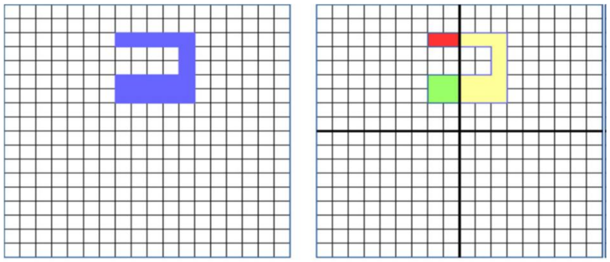
The comparison of *GT* and *TS* is made by using the Hoover metrics [6]. *RC* is the score of correct segment matches. The scores of the metrics range from 0 to 1. *RC* = 1 means that both segmentations are identical. The procedure to ensure that this property is fulfilled consists of stabilizing segmentation algorithms [4].

Let *I* denote an image and *S: I* → *S* (*I*) represent a segmentation algorithm. *S* (*I*) forms a partition of *I* into homogeneous disjoint segments$(R_1, \dots, R_n)$, where R_i is one of these segments. *T* ⊂ *I* denotes a tile, i.e., an image subset of *I*. A segment *R'* from the segmentation of *T* is represented by *R'* ∈ *S*(*T*). For a segment *R* ∈ *S* (*I*) and a tile *T* ⊂ *I*, we define $S_R(T)$ as follows:

$$S_R(T) = \{R' \epsilon S(T) \backslash R' \subseteq R\} \qquad (4)$$

$S_R(T)$ is the set of segments *R'* ∈ *S*(*T*) that are fully included in segment *R* ∈ *S*(*I*). With these notations, the authors in [4] define a stable segmentation algorithm as follows:

Definition of a stable segmentation algorithm *:* Algorithm *S* is said to be stable if ∀*R* ∈ *S*(*I*) and ∀*T* ⊂ *I*, the following properties hold:



Reference segmentation Tiled segmentation

Fig.1.Cover stability property. The segment from the reference segmentation is the union of segments from the tiled segmentation located on the tile borders.

$R \subset T \Rightarrow \exists R' \epsilon\, S(T) \backslash R' = R$ (5)
(6)

Equation (5) represents the inner stability property, and (6) represents the cover stability property. Fig.1 illustrates the cover stability property.

2) *Expression of the Stability Margin for Region-Merging Algorithms:* For a given segment *R*, its best adjacent segment will not be found farther from its list of adjacent segments. Let N(R) be the union of all these segments for each segment in a tile ensures the stability of the region merging segmentation to perform one iteration [1]. The stability margin to perform the first iteration is therefore a crown of two pixels around each segment.

Let M_n be the size of the margin to perform the first *n* iterations. The objective is to determine the size of margin $Mn+1$ for next iteration. The upper bound for the number of pixels contained in segment after *n* iterations is equal to $2n$. This upper bound is reached if the segment merges at each iteration with a segment containing the maximum number of pixels. $Mn+1$ can be expressed in function of M_n as follows:

$Mn+1 = 2n+1 + M_n$, with $M0 = 0$ (7)

which can be written as

$Mn+1 = 2n+2 - 2$ (8)

B. Tiling approach for Region-Merging Segmentation Algorithm

1) *Region-Merging Segmentation Algorithm with Tile-Based Framework:* We consider the following algorithm steps for large scale segmentation.

a) Dividing the input image in to number of tiles with their additional stability margin.
b) The stabilized mean-shift filtering algorithm is applied to each tile.
c) Partial segmentation is applied to each filtered tile for first iteration. As a result of these segmentations, graphs of segments are obtained and contain both stable and unstable segments [1]. Unstable segments must be removed from the graphs. These graphs are then written to files for next iteration.
d) The number of iterations are performed on each tile, until there are no homogeneous segments to merge together. Relabeled graphs of segmented tiles.
e) Merging all the graphs to form one graph of the segments of the tiles.

2) *Merging the Graphs:* Merging two or more graphs can happen when a stability margin is added to a graph, when the graphs of the tiles are merged to form the graph of segments of the input image.

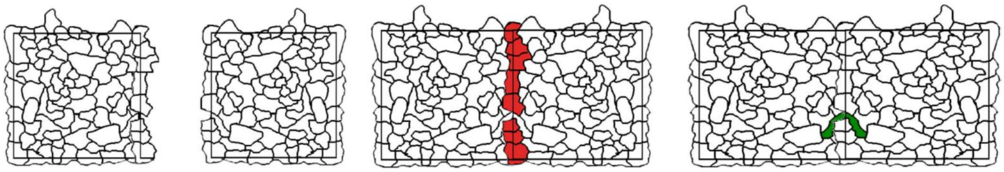
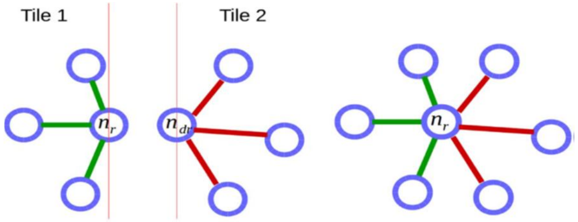

(a) (b) (c)

Fig.2. Aggregation of two graphs of segments. (a) Graphs to be aggregated. (b) Processing of duplicated segments. (c) Update of missing edges.



(a) (b)

Fig.3. Graph operation for duplicated segments.

Fig. 2(a) represents a pair of graphs to be merged. The segments that overlap the common borders between the adjacent tiles are duplicated [see Fig. 2(b)]. Let N_d be a segment and L_{Nd} be the list of its duplicated segments. The merging operation consists of updating the list of the edges of N_d by exploring the list of the edges of the nodes contained in L_{Nd} [see Fig. 3(a)]. Once the edges of $N_d$are updated, the nodes contained in L_{Nd} can be removed [see Fig. 3(b)].

The segments that contain pixels exactly on one side of the borders without overlapping. Their neighborhoods

have to be updated by detecting the adjacent segment on the other side of the borders. An edge is then added between their corresponding nodes [see Fig. 2(c)].

IV. EXPERIMENTS AND RESULTS

We consider a 763 × 763 QuickBird image I of Eifel Tower as shown in figure 4. and the Baatz and Schäpe

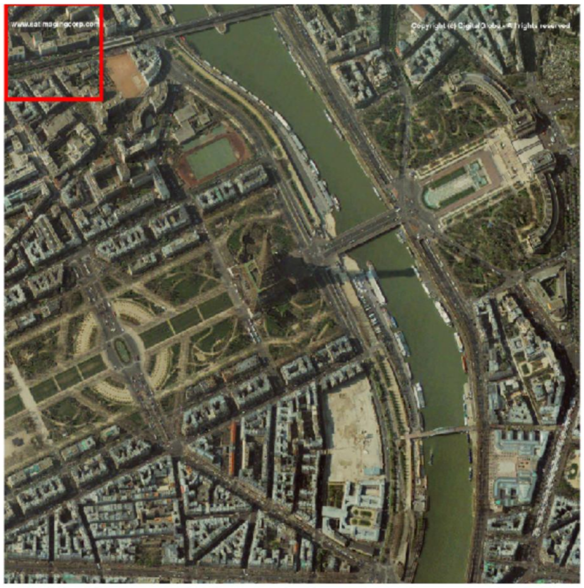


Fig.4. Division of the image scene of size 763 × 763 pixels into 36 tiles of size 125 × 125 pixels. The red rectangle represents one of the tiles of the image.

(a) (b)

Fig.5. (a) segmented image obtained without image tiling (b) Segmented image after applying our tile-based region merging framework. No artifacts can be observed at the tile boundaries. Both results (a) and (b) have been compared with the Hoover metrics: *RC* = 1. The equivalence of the result is proven.

Criterion [5] for our region-merging algorithm with a spectral and shape weight of 0.7 and 0.3, respectively, and a scale threshold of 60.

We apply the following procedure.

1) The segmentation of the whole image *I* is performed at once. We call *GT* the segmentation result. We extract from *GT* a tile of size 125 × 125 pixels. We call it *ET*.

2) We extract a tile from the image covering the same zone as *ET*.

As described in Section III-B1, the next step consists of performing the partial segmentations of the tiles with stability margins of 125. At the end of this step, the unstable segments are removed from each graph, and the graphs of the tiles are stored on the SUS.

The final step consists of merging all the intermediate graphs together to form the global graph of the image. Fig.5 (b) shows the segmented image. We notice the absence of the artifacts at the tile boundaries. Furthermore, we compare this segmentation result with the one obtained from the segmentation of the whole image without tiling [see Fig.5 (a)] using the Hoover metrics [6]. A correct detection score *RC* = 1 has been obtained, which means that both segmentations are identical.

V. CONCLUSION

The concept of stability margin has been defined and expressed quantitatively as a function of the number of iterations of the region-merging procedure. Using the stability margin in a tiling approach has allowed ensuring the equivalence of the results between the segmentation with and without tiling. The practicality of the tile-based framework for region-merging algorithms has been illustrated by the segmentation of a full entire QuickBird scene with limited storage of computer memory.

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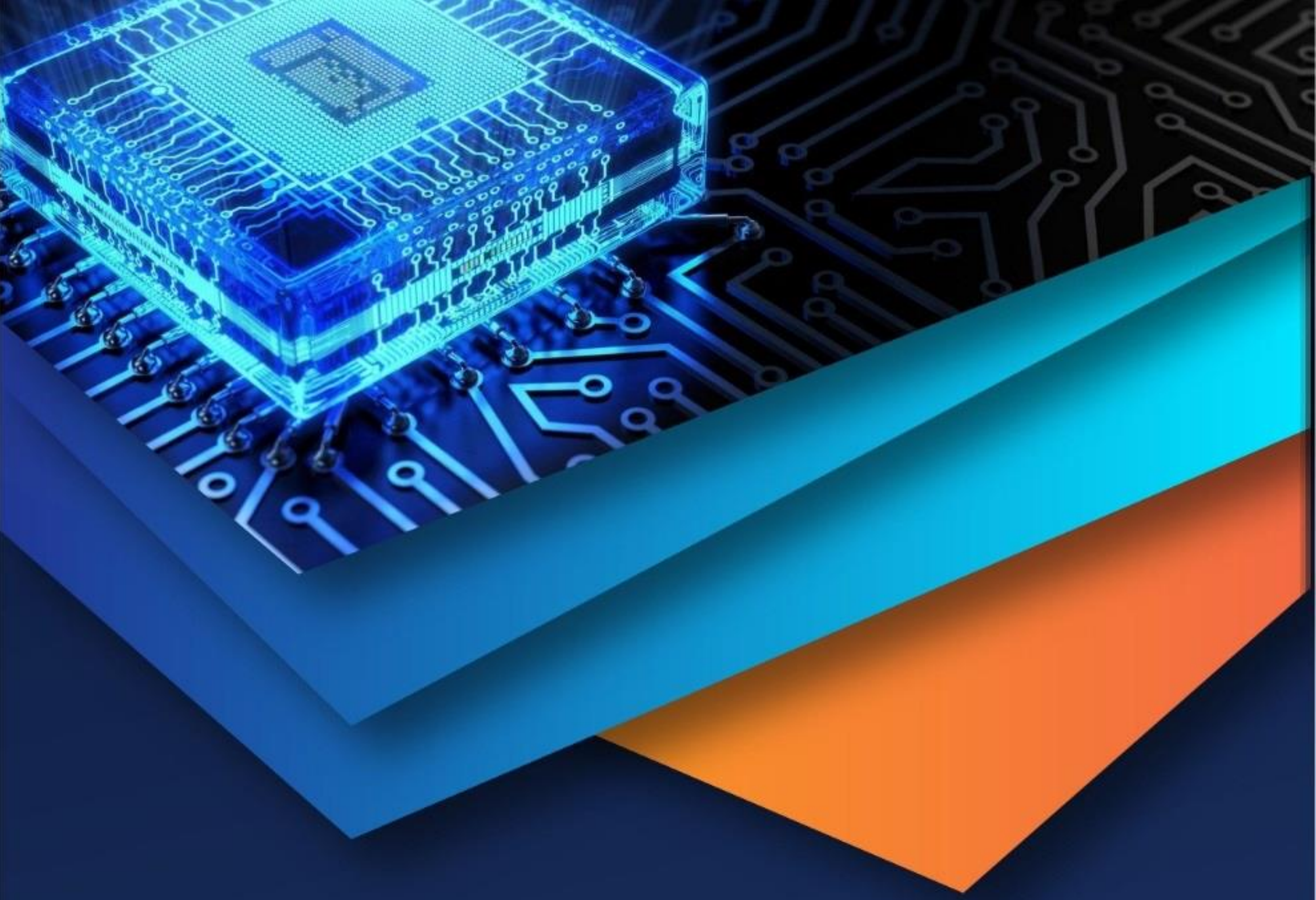

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