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Watershed regions and watershed lines based cooperation strategy for image segmentation. Application to roof detection

Y.El-merabet and C.Meurie and Y.Ruichek and A.Sbihi and R.Touahni

Abstract—In this paper, we present a strategy of image segmentation for roof detection from aerial images. For that, an orthophotoplan segmentation method based on a cooperation technique including edge based segmentation and region based segmentation is proposed. Both segmentation techniques are assured by watershed algorithm. The proposed strategy is composed of three steps: (i) A simplification step that consists in simplifying the image with an appropriate couple of invariant/gradient optimized for the application. (ii) The second step is composed of two main treatments: On the one hand, the image is segmented by the watershed regions coupled with an efficient regions merging technique. On the other hand, the image is segmented by the watershed lines. (iii) The third step consists in exploiting the advantages of each method and thus achieve a reliable segmentation results. Tests have been performed on an orthophotoplan containing 100 roofs with varying complexity and evaluated with Vinet criteria using a ground truth image.

Index Terms—Watershed, modeling, orthophotoplans, region merging, cooperation.

I. INTRODUCTION

Image segmentation consists in partitioning an image in more or less regular or homogeneous regions according to a given criteria. Many segmentation methods exist in the literature and can be generally grouped into two categories: edge-based and region-based segmentation. The first category consists of detecting the dissimilarity in the image. It generally assumes an a priori knowledge of a model to detect and operates on very localized edges. Its major drawback concerns the sensibility to noise which leads to contours that are generally not closed [15]. The second category of methods consists in grouping adjacent pixels according to a certain similarity criteria. The advantage of this approach is that it provides a map of regions. Among the morphological techniques most frequently used, one can cite split/merge and region growing [16]. However, the localization of the region boundaries remains generally imprecise [7]. This can be justified by the difficulty to define the best criteria or parameters in the split/merge or pixels aggregation strategies [2]. The choice of the segmentation method is closely related

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to the particularities of the images and the considered application. Nevertheless, for specific applications such as the roof detection in aerial images, using a single segmentation technique (edge or region based segmentation) is generally insufficient to obtain the best results. For this reason, a cooperation between different segmentation techniques can be suitable in order to exploit their advantages, and then, improve the quality of the segmentation. Many segmentation approaches combining the results generated from several techniques have emerged in recent years. Indeed, the robustness of the treatment is greatly improved by the use of several hybrid segmentation methods [1], [4], [14], [16], [22], [24]. Segmentation based on region-edge cooperation permits to exploit the two complementary informations in order to integrate them in the same segmentation scheme and thus contribute to a better segmentation [3], [6], [18], [21], [23]. The work presented in this paper is developed within a global approach that consists in recognizing roofs in aerial images using a knowledge database and bending out 3D models automatically generated from geographical data. The main step presented in this paper consists in segmenting roof images in different regions of interest in order to provide several measures of roofs (section of roofs, chimneys, roof light, etc). Recent works of the authors have shown that segmentation based on region growing using watershed algorithm gives results [12]. This paper proposes a segmentation method based on a edge/region cooperation strategy. Figure 1 illustrates the objective of the segmentation process within the considered application: orthophotoplan image (left), zoom of roof to detect/extract (middle) and ground truth image segmentation (right).

The paper is organized as follows: Section II presents the segmentation step using regions growing. In this section are detailed: 1/ initial segmentation using watershed algorithm, 2/ 2D modeling of roof ridges strategy, 3/ an efficient regions merging process that improves segmentation results, 4/ a segmentation technique using a strategy of edge detection is detailed. In section III, we describe the cooperation technique based on the two segmentation (region based and edge based). Experimental results are shown in section IV. Section V concludes the paper and presents future works.

II. WATERSHED SEGMENTATION

Among all the existing image segmentation approaches, we have chosen mathematical morphology framework. Indeed, regions growing based segmentation methods seem to be more adapted when considering the objectives of our



Fig. 1. Objective of the segmentation process. (left to right: an ‘‘orthophotoplan’’ image, zoom of a roof, ground truth image segmentation).

application. In the following, we propose a segmentation strategy based on watershed algorithm.

A. Initial segmentation using watershed regions

In order to obtain a preliminary orthophotoplan segmentation, we have used Meyer’s algorithm [13] which is an efficient mathematical morphology technique. It is based on a simple heuristic that consists in analyzing the gray level pixels of the image in ascending order. Performing regions growing, the watershed algorithm uses a gradient image and a seed image. In our previous works [12], we have studied the influence of the gradient image on the watershed algorithm in the framework of roofs detection. For that, a several tests have been performed to define the best gradient among 14 gradients of the literature (eight gray level gradients and six color gradients). In order to extract correctly the different regions of interest of a roof image and limitate illumination changes and shadow effect, we apply a suitable colorimetric invariant to the initial image. Several tests have been performed to choose an appropriate colorimetric invariant among a set of 24 invariants of the literature. These tests have allowed to validate the interest to use an appropriate couple of colorimetric invariant/gradient in the segmentation process. The tests concluded that the couple Maximum-intensity/Di-zenzo gives the best segmentation results when applying watershed to the orthophotoplans for roofs detection. Table I illustrates some examples of segmentation results using couples of invariant/gradient. The results are expressed by Vinet criteria [20]. One can notice that the best results are obtained with the couple Maximum-intensity/Di-zenzo (see [12] for more tests and details). Figure 2 shows the segmentation results on five images of the database. Based on Di-zenzo’s gradient, the presented results are obtained without/with the Maximum-intensity invariant.

TABLE I
MEAN VALUES OF VINET CRITERIA.

Invariant \ Gradient	Carron	Di-zenzo	MGradient	SobelC
RGB	90.3%	92%	91.5%	90.4%
Greyworld	93.6%	93%	94.3%	94.4%
MaxRGB	92%	94%	92.5%	93.2%
M-intensity	93%	96%	93.3%	93.5%
RGB-rang	77.6%	82.6%	84.7%	80.4%
hsl	68%	64%	76.4%	68.6%
c1c2c3	58.5%	62.8%	67.7%	64.3%
m1m2m3	53.6%	58.7%	60.6%	53.7%
l1l2l3	52.8%	53.8%	61.8%	56.6%

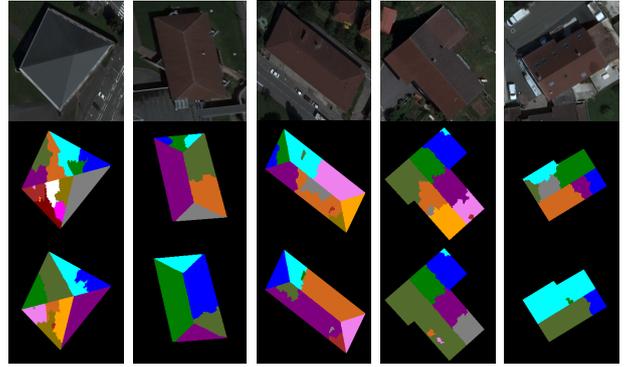


Fig. 2. Example of Di-zenzo’s gradient based segmentation without/with colorimetric invariant. (top to bottom: initial image, segmented image without invariant, with Maximum-intensity normalization).

B. 2D modeling of roof ridges

2D modeling of roof ridges depends exclusively on the segmentation results obtained in the previous step. It consists in calculating a 2D model describing the roof ridges by segments where each ridge is represented by only one segment. Initially, the modeling process consists in extracting the edges of the pre-segmented image obtained previously. After that, it transforms all edges into segments whose extremities are nodes that connect the roof ridges. More precisely, the modeling strategy is composed of three steps described below:

- 1) Edges extraction in the pre-segmented image: this step heavily depends on the quality of the pre-segmented image. The edge extraction is performed by scanning the image into the two x and y directions. A pixel located in a transition state between two different regions is considered as a border pixel (cf. figure 5c).
- 2) Extraction of segments and intersection points: this step consists in detecting all intersection points characterizing a roof and transforming the edges into segments. This is achieved by a recursive process that consists first in choosing arbitrarily a border point as a starting point for a segment. Then, we add to this point, all neighbors points until obtaining zero non-affected points. The path direction is reversed in order to adjust the starting point chosen arbitrarily. A point on which the path direction is reversed or the creation of a segment is stopped is considered as intersection point (extremities of the segment). The process is repeated until there are no points to affect.
- 3) Segments subdivision: this step allows subdividing the segments which do not characterize the real shape of the roof. It consists to modifying/optimizing the position of the intersection points connecting several ridges by maximizing the sum of the segment lengths.

Figure 3 illustrates an example of 2D modeling of roof ridges. One can notice that the straight line aspect of a boundary of two regions belonging to two main roof sections is always respected (for example the roof sections labeled by the numbers 7 and 8 in figure 5e). Thus, this boundary is characterized at most by two segments. The straight

line aspect is not respected when it concerns a boundary separating two regions resulting from an over-segmentation (for example, the roof sections labeled by the numbers 8 and 9 in figure 5e). In this case, this boundary is characterized at least by five segments.

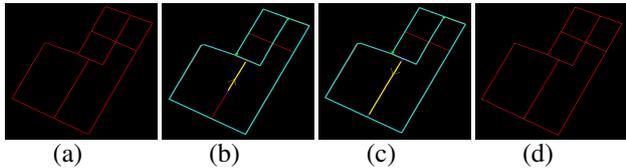


Fig. 3. Example of segments creation. (left to right: edge extraction after pre-segmentation step (a), a starting point (b), inversed direction path (c), obtained 2D model (d)).

C. Regions merging

Unfortunately, the watershed transformation usually produces an important over-segmentation in the image. This problem is due to a large numbers of local minima. Many solutions have been proposed in the literature to overcome this drawback [5], [8], [9], [10], [11]. Most of them consist in filtering the input image before using the watershed algorithm, or applying a region merging technique after the watershed algorithm. In this context, we propose a region merging strategy based on the region adjacency graph (RAG) of the pre-segmented image and a merging criteria adapted to orthophotoplan particularities. Since a ridge separating the roof sections correspond to a line segment. A simple merging criteria consists in merging the neighboring regions when the common boundary is not a line segment. Our merging strategy takes into account the number of segments modeling the boundary between two regions candidate to the fusion. Indeed, for two adjacent regions, we extract their common boundary, and count by the modeling technique the number of segments. If the number of segments is greater than 1, the two regions are merged. A drawback of this merging criterion is that it produces an under-segmentation of the image. This problem is generally due to a poor quality of the extracted ridges which can be caused by the non-detection of a roof light or a chimney located on a boundary. Thus, this boundary is also modeled into several segments. For example, in figure 5, the non-detection of the window located between the regions labeled by the numbers 2 and 8, leads to a boundary modeled by 3 segments. To deal with this problem, other informations on the boundaries and regions can be exploited: the mean difference of two regions belonging to two different roof sections (for example, regions labeled 7 and 8 in figure 5e) must be much lower than the contrast observed on the common boundary. On the contrary, if we consider a boundary between two regions resulting from an over-segmentation (for example, regions labeled 8 and 9 in figure 5e), the propriety mentioned above is not respected. Figure 4 shows that the segmentation results obtained with the regions merging strategy are better than those obtained without this strategy. The synopsis of the region merging strategy is illustrated in figure 7 by a dashed

line section in yellow. The regions merging algorithm is given below:

- Im is a gradient image.
- δ_{seg} is the number of segments modeling the common boundary between the regions R_1 and R_2
- ξ_{R_1, R_2} is the contrast on the boundary between the regions R_1 and R_2 . $\xi_{R_1, R_2} = \frac{1}{\eta} \sum_{p1 \in R1} \max_{p2 \in V_{p1}, p2 \in R2} (|Im(p1) - Im(p2)|)$ where η is the number of pixels of the common boundary between the regions R_1 and R_2 .
- $\bar{\varrho}_{R_1, R_2}$ is the mean difference of the regions R_1 and R_2 . $\bar{\varrho}_{R_1, R_2} = |\frac{1}{\eta_1} \sum_{p1 \in R1} Im(p1) - \frac{1}{\eta_2} \sum_{p2 \in R2} Im(p2)|$, with η_1 and η_2 are respectively the number of pixels of the regions R_1 and R_2 .

Algorithm 1: Regions merging algorithm

```

 $\delta_{seg} \leftarrow \text{Modeling}(\text{boundary}(R_1, R_2));$ 
 $\bar{\varrho}_{R_1, R_2} \leftarrow \text{abs}(\text{Mean}(R_1) - \text{Mean}(R_2));$ 
 $\xi_{R_1, R_2} \leftarrow \text{Contrast}(\text{boundary}(R_1, R_2));$ 
if  $\delta_{seg} \geq 5$  OR ( $\xi_{R_1, R_2} \leq \bar{\varrho}_{R_1, R_2}$  AND  $4 \leq \delta_{seg} \leq 3$ )
then
    the region with a minimum label absorbs the region
    with the maximum label
    \ \ update the label of the absorbent region

```



Fig. 4. Evaluation of the segmentation results (with Vinet criteria) according to the watershed regions (in red) and the regions merging strategy (in green).

D. Segmentation using watershed lines

In order to calculate the image of edges, we have used the algorithm introduced by Vincent and Soille [19], [17] and which belongs to watershed algorithms by immersion. The gradient image is considered as an altitude map or a topographic relief. The gradient is used to distinguish homogeneous and heterogeneous zones of the image. The gradient

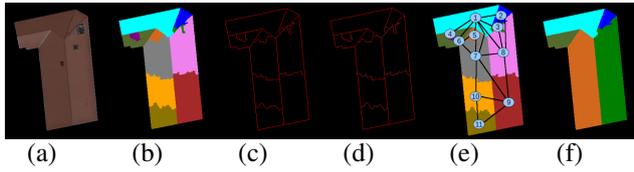


Fig. 5. Region merging strategy. (a) initial image, (b) segmented image by the watershed algorithm, (c) edges extraction, (d) model of segments, (e) RAG of the pre-segmented image, (f) final segmentation.

is more important if the pixels is located in a heterogeneous zone. The relief is flooded from the minima of the gradient image. When two retention bassins meet, a watershed line is created to separate them. The advantage of the watershed lines segmentation is that it leads to a closed and fine adjacent contours including all image edges. Nevertheless, the major drawback of this method is the high sensitivity to noise and local irregularities in the gradient image which implies generally an over-segmentation. Figure 6 illustrates some segmentation results obtained with the watershed lines based algorithm. One can notice that the majority of roof objects are detected. However, the algorithm produces a strong over-segmentation of the roofs.

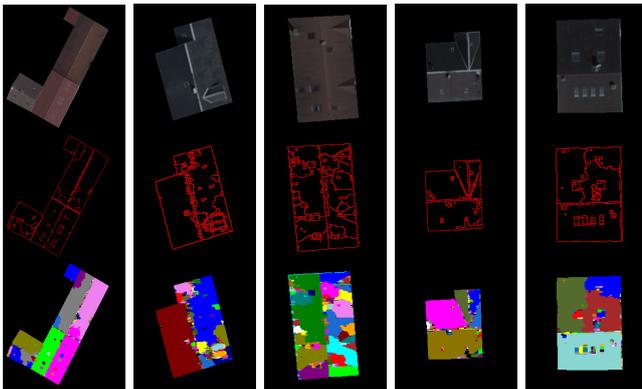


Fig. 6. Segmentation results with watershed lines. Top to bottom: initial image, edges segmentation and corresponding labeled image.

III. WATERSHED REGIONS AND WATERSHED LINES COOPERATION

In the previous section, we have presented the watershed regions, the watershed lines and the region merging strategy. These methods will be integrated into a single cooperative segmentation scheme to achieve satisfactory segmentation results. Indeed, this region/edge cooperative process will be able to exploit the advantage of each segmentation method. The watershed regions segmentation coupled to the region merging strategy allows dealing with the over-segmentation problem in the orthophotoplans. The main drawback of this segmentation strategy concerns the loss of chimneys, roof light, and some roof sections. These components are either lost in the regions merging step or not detected by the watershed algorithm. The non-detection of these components can be justified by the lack or a bad position of seeds. The watershed lines has been introduced to overcome this drawback. Indeed, it allows detecting the majority of the roof

components but produces an important over-segmentation on the boundaries between the different roof sections. To improve the quality of the orthophotoplans segmentation a cooperation between the two segmentation strategies described above is suitable. Figure 7 illustrates in three steps, the principle of the cooperation process between the watershed regions and the watershed lines:

- 1) The first step consists in preparing the input image to the two watershed algorithms (regions and lines). It applies on the initial image the best couple of invariant/gradient (Maximum-intensity/Di-zenzo) such as defined in [12].
- 2) The second step consists in segmenting the image by the watershed regions and watershed lines. These two segmentation techniques are applied in an independent and parallel way. On the one hand, the image is segmented by the watershed regions and then the regions merging process is performed in order to limit the over-segmentation phenomena. At this step, we obtain a segmented image called A. On the other hand, the image is segmented by the watershed lines coupled with an extraction of regions (each closed edge permits to obtain a region). From the produced segmented image, the barycenter of each region is calculated. Then, the barycenters corresponding to regions with a surface that is inferior to a certain threshold are deleted. This step allows keeping only barycenters of regions which correspond to roof lights, chimneys and roof sections that are not detected by the watershed regions. Finally, a watershed regions is applied again on the seed image obtained by overlapping the barycenters extracted above and those located in the segmented image A. This last step performs a first watershed regions and watershed lines cooperation, and produces a segmented image called B. The image contains the roof components which are not detected by only the watershed regions.
- 3) The final step reflects a second watershed regions and watershed lines cooperation. Indeed, edges of the segmented image A are exploited to remove small regions due to the fluctuations of intensity on the boundaries of the segmented image B. To do this, each barycenter of region of the segmented image B that coincides with an edge-pixel of the segmented image A is deleted. Then, a watershed regions is applied again on a seed image containing the new barycenters of the previous image. This produces a segmented image called C. To conclude, the final segmentation is produced by overlaying all regions of the segmented image A and the regions of the segmented image C with a surface lower than a certain threshold.

IV. EXPERIMENTAL RESULTS

In this section, we present several tests in order to validate and prove the effectiveness and the reliability of the proposed segmentation approach. The tests have been performed on one orthophotoplan provided by "Communauté

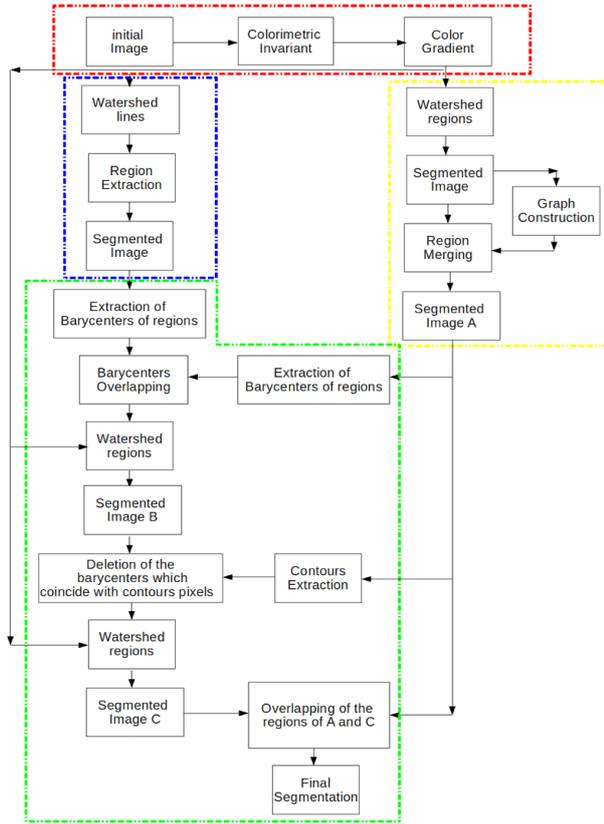


Fig. 7. Synopsis of the watershed regions and watershed lines cooperation.

de l'Agglomération Belfortaine" (CAB 2008) and containing 100 heterogeneous roofs with varying complexity. Segmentation results have been evaluated with Vinet criteria [20] including a ground truth image (segmented by an human expert). The main aim consists in obtaining a segmentation result that is faithful to the orthophotoplan (roof sections, chimneys, etc.).

Figure 9 illustrates the evaluation results obtained on 100 roofs using Vinet criteria. The graph shows clearly that the proposed cooperation approach allows obtaining the best segmentation results. Indeed, Vinet value is higher for the segmented image obtained with the cooperation process compared to that produced with only one segmentation technique. For one image of the database, the segmentation obtained by the cooperation process is less better than the segmentation obtained by the watershed regions. In the case of the watershed lines, the segmentation obtained by the cooperation process is less better for four images of the database. In terms of quality of segmentation, we obtain a rate of 96% with the proposed cooperation procedure VS 83% with only the watershed regions VS 88% with only the watershed lines. These rates are confirmed by the segmentation results presented in figure 8. One can see that the segmentation results obtained with the cooperation procedure are better than those calculated with only one segmentation strategy. Indeed, the segmentation results based on the cooperation procedure (images of the last row of figure 8) confirm the

conclusions of figure 9. The segmentation results obtained only with the watershed regions are not satisfying since the images are over-segmented (cf figure 8, row 2). The region merging procedure allows increasing the results, but several objects of the roofs as roof lights, chimneys, etc are lost (cf figure 8, row 3). The segmentation results obtained only by the watershed lines allows keeping these objects but produces an over-segmentation and noise (cf figure 8, row 4). As contrary, the segmentation results obtained with the cooperation procedure gives the best results. The images are well segmented and most of roof lights and chimneys are present (cf figure 8, row 5).

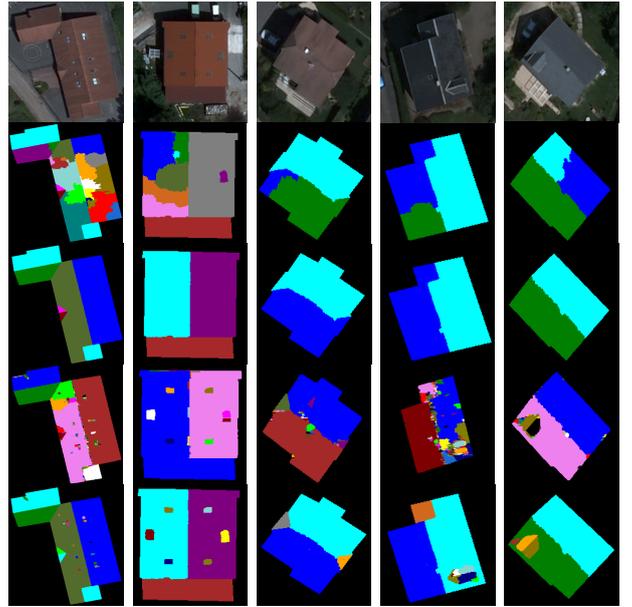


Fig. 8. Segmentation results based on the proposed cooperation procedure. From top to bottom, initial images, images obtained by the watershed regions, images obtained after regions merging step, images obtained by the watershed lines and images obtained with the proposed cooperation procedure.

V. CONCLUSION

An image segmentation method based on a cooperation between watershed regions and watershed lines is presented. This segmentation method is proposed in the field of "orthophotoplan" segmentation for roof detection. This cooperation strategy takes into account the advantages of the two segmentation methods (watershed regions and watershed lines coupled with an appropriate couple of colorimetric invariant/gradient). The cooperation strategy allows obtaining a better detection of several objects of the roofs (such as roof lights, chimneys, etc). One can conclude that the segmentation results obtained by this approach are very satisfying and faithful to the reality. Indeed, we obtain a rate of 96% with the proposed cooperation procedure VS 83% with only the watershed regions VS 88% with only the watershed lines.

VI. AKNOWLEGMENTS

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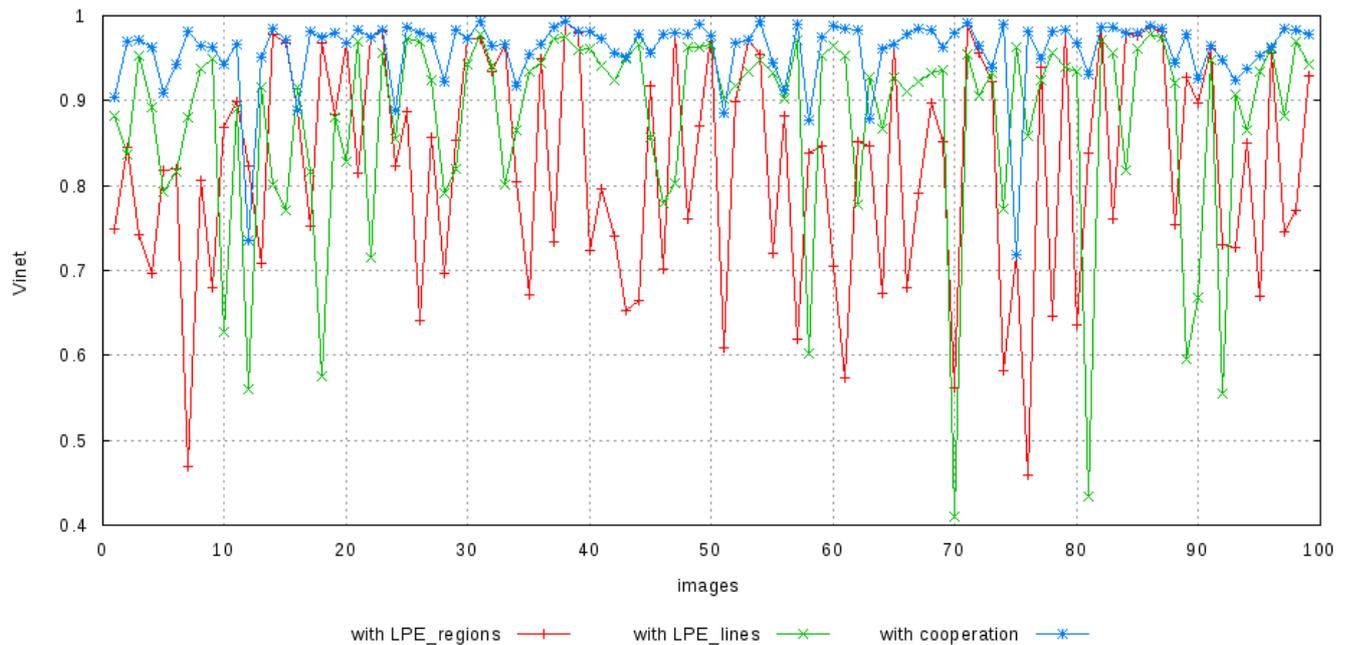


Fig. 9. Evaluation results (with Vinet criteria) of the segmented images according to the watershed regions (in red), watershed lines (in green) and cooperation strategy (in blue).

d'agglomération Belfortaine” for the “orthophotoplan” images on which the tests have been performed.

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