Road segmentation from satellite aerial images by means of adaptive neighborhood mathematical morphology

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Abstract

In this paper, we present a methodology for segmenting the road from satellite aerial images using Adaptive Neighborhood Mathematical Morphology (ANMM) dealing with multiscale image processing. It is increasingly accepted that accurate image of the road networks enables the study of the entire or a congested part of the cities. This is possible with the help of an aerial image. There is a strong demand to automate acquisition and update of road date. The System used in this paper is a fully automatic that extracts road information using the concept of adaptive neighborhood techniques. A study is also conducted to find its efficiency compared to other road tracking methods using region competition/ region segmentation techniques. The basic idea in this approach is to substitute the extrinsically defined – shape , fixed – size structuring elements generally used for morphological operators. The last ones should fit to the local multi scale features of the image, with respect to a selected criterion such as luminance, contrast, thickness and curvature. Our aim is to extract as many roads as possible independent of how wide and how sinuous changes of the roads.

Key words: Multi scale morphology, adaptive neighborhood , structuring elements

I. INTRODUCTION

Mathematical morphology (MM) is an important and a traditional framework in the general image processing field The development of MM leads to several processing tools in the aim of image filtering , image retention and classification, usage measurements, pattern recognition, or texture analysis and synthesis. The morphological operators of the early form have the draw backs of grating artificial patterns and distorting or removing significant details to cope with the problems, we propose the new morphological operators using Adaptive neighborhood concepts. The proposed method uses new type of opening and closing operators (NOP & NCP)

II. ADAPTIVE NEIGHBORHOOD MATHEMATICAL MORPHOLOGY.

In this paper, only the flat MM (ie with structuring elements as subsets in $\mathbb{R}^2$) is considered, through the approach is not restricted and can also address the general case of functional MM (ie with structuring elements as subsets in $\mathbb{R}^2$and functions from D into $\mathbb{R}$) .

The space of images I is provided with the partial ordering relation $\leq$ defined in terms of the usual ordering relation of real *numbers:*

$\forall\ (f, g) \in I \quad f \leq g \Leftrightarrow \quad (\forall\ x \in D \quad f(x) \leq g(x)$

Thus, the partially – ordered set (I, $\leq$), still named I, is a complete lattice

A. Adaptive structuring Elements

Applying the Adaptive Neighborhood (AN) principle to the construction of morphological operators, the (adaptive) structuring elements (SEs) should be defined according to these AN sets. To get the morphological duality between (adaptive) erosion and (adaptive) dilation, we should use reflected SEs. Since the AN sets $\{V_m^h(x)\}_{x \in D}$ are spatially well-adapted, fitting to the local contextual details of the image, the reflected ones could naturally not be envisaged. Therefore, the adaptive SEs$\{R_m^h(x)\}_{x \in D}$ have to be symmetric while respecting the AN paradigm :

$$\forall\ (m,h,x) \in R^+ \times C \times D$$

$$R_m^h(x) = \bigcup_{z \in D} \{V_m^h(z) \mid x \in V_m^h(z)\}$$

These adaptive SEs [3] are anisotropic and self – defined with regard to the criterion image mapping h, and satisfy the following properties:

1) reflexivity:
$$x \in R_m^h(x)$$
2) geometric nesting :
$$V_m^h(x) \subseteq R_m^h(x) \subseteq V_{2m}^h(x)$$
3) symmetry:
$$x \in R_m^h(y) \Leftrightarrow y \in R_m^h(x)$$
4) increasing with regard to m:
$$m_1 \leq m_2 \Rightarrow R_{m1}^h(x) \subseteq R_{m2}^h(x)$$
5) translation invariance:
$$c \in \mathbb{R} \Rightarrow R_m^{h+c}(x) = R_m^h(x)$$
6) multiplication compatibility :
$$\alpha \in \mathbb{R}_+ \setminus \{0\} \Rightarrow R_m^{\alpha h}(x) = R_{\frac{m}{\alpha}}^h(x)$$

On the whole, Figure 1. compares the shape of usual and adaptive SEs:

The next step consists in defining basic adaptive operators of MM in the aim of building (adaptive) multiscale morphological filters.

B. B. Elementary Adaptive Morphological Operators and Filters

The elementary dual operators of adaptive dilation and erosion, we are going to use. Are respectively defined as:

$\forall\ (m,h,x) \in \mathbb{R}^+ \times C \times I$

$$D_m^h(f) : \begin{cases} D \rightarrow \mathbb{R} \\ x \mapsto \sup_{w \in R_m^h(x)} f(w) \end{cases} \quad (1)$$

$$E_m^h(f) : \begin{cases} D \rightarrow \mathbb{R} \\ x \mapsto \inf_{w \in R_m^h(x)} f(w) \end{cases} \quad (2)$$

Next, the lattice theory allows to define the most elementary (adaptive) morphological filters. More precisely, the adaptive closing and opening are respectively defined as:

$\forall\ (m,h,f) \in \mathbb{R}^+ \times C \times I$

$$C_m^h(f) : \begin{cases} D \rightarrow \mathbb{R} \\ x \mapsto E_m^h(f) \circ D_m^h(f)\ (x) \end{cases} \quad (3)$$

$$O_m^h(f) : \begin{cases} D \rightarrow \mathbb{R} \\ x \mapsto D_m^h(f) \circ E_m^h(f)\ (x) \end{cases} \quad (4)$$

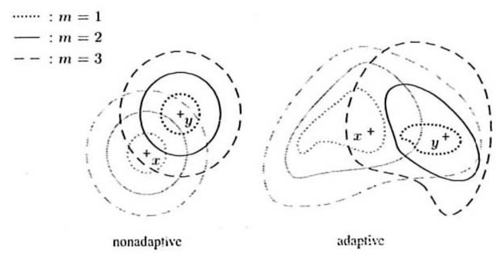

Figure 1. Example of non adaptive and adaptive structuring elements for three values of the homogeneity tolerance parameter *m*

Moreover, the adaptive (with the 'luminance' criterion) dilation (1) and erosion (2) possess a property of great morphological importance:

$$\left. \begin{array}{l} f \mapsto D_m^f(f) \\ f \mapsto E_m^f(f) \end{array} \right\} \text{are connected operators}$$

Indeed, for all (x,y) neighboring points (with the usual Euclidean topology on $D \subseteq \mathbb{R}^2$), if $f(x)=f(y)$. Then $R_m^f(x) = R_m^f(y)$. so, $D_m^f(f)(x) = D_m^f(f)(y)$ and $E_m^f(f)(x) = E_m^f(f)(y)$.

Consequently, it allows to define connected morphological operators built by composition or combination with the supremum and the infimun of these ones, as adaptive closings (3) and openings (4) . Thus , the operators $OC_m^h = O_m^h\, C_m^h$ and $CO_m^h = C_m^h\, O_m^h$, called adaptive opening-closing and adaptive closing - opening respectively , are (adaptive) morphological filters, and in addition, connected operates with the 'luminance' criterion.

III. ROAD SEGMENTATION

A. *Fully Automatic Approach for road extraction*

There is a strong demand to automate acquisition and update road data. Despite a lot of research work has been done on semi- and fully automatic approaches for road extraction, the desired high level of automation could not be achieved by now. The main problem of fully automatic approaches is that for many applications the quality of the result is not sufficient. Some parts of the road network are missed and some parts are erroneous. The algorithm used in this paper combines adaptive morphological filters and cross-curvature evaluation to segment the road. Apart from the adaptive neighborhood multiscale morphological basic operators are used (as defined in II), the algorithm is also using geodesic reconstruction (or opening) which is defined by

$$\gamma^{rec}_{Sm}(S) = \sup_{d \in N} (\Delta^{d}_{Sm}(S))$$

Δ^{d}_{Sm} - Geodesic dilation of the image

Similarly geodesic closing is defined by

$$\varphi^{rec}_{Sm}(S) = N_{max} - \gamma^{rec}_{(Nmax-Sm)}(N_{max} - S)$$

N_{max} and N_{min} are the maximum and minimum values of a 2D (two - dimensional)image

B .Morphological filters with adaptive structuring elements.

Recognition of linear parts: Linear bright shapes can easily be identified using adaptive neighborhood mathematical morphology. (ANMM). An opening using a adaptive structuring element will remove a road or part of it when the non- adaptive linear structuring element cannot be included inside the road path, when they have orthogonal directions and the structuring element is longer than the road width.

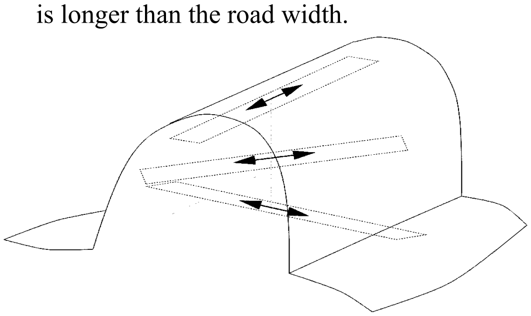

Figure 2 . Opening using linear structuring elements

Conversely, when the structuring element and the road path are in parallel , the path is retained as seen in the above figure 2 . If we consider the openings along a class of adaptive structuring elements, a sum of top – hats along each direction will brighten the road paths regardless of their direction. Since the length of the structuring element is applied in multiscale mode, the unwanted edges are removed and a lot of noise is removed in the sum of top hats. For this we use the connectivity property to preprocess the image

original image

Figure 3 (a) Initial image of Mysore city

supremum of openings

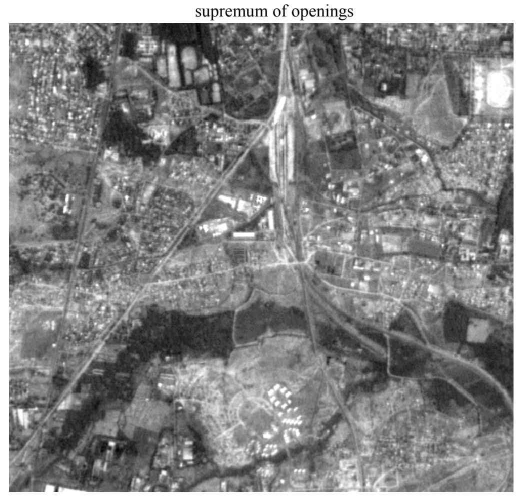

Figure 3 (b) Supremum of openings

FFigs . 3(a) –(d) Each Step of the ANMM treatment images

Using the connectivity property : We remove the noise while preserving most of the hair like road paths using a geodesic reconstruction of the opened images into the original image S_o :

$$S_{op} = \gamma^{rec}_{So} (\mathrm{Max}_{i=1,\ldots,12} \{ \gamma_{Li} (S_o) \})$$

Each adaptive structuring element Li (every15^o) is varied in its length from 15 to 30 in multiscale and 2 pixels wide [3]. In the geodesic reconstructed image , S_{op} , every isolated round and bright zone whose diameter is less than 15 pixels will be removed . Being a supremum of openings by reconstruction this operation is an adaptive opening with multiscale from 15 to 30 . This adaptive opening removes white noise and some abnormalities such as small bright and dark areas . The sum of top hats on the filtered image S_{op} will enhance all the roads whatever their direction , including small or tortuous roads , even in the low signal /noise ratio concerning the intensity of the roads .The back ground features that may be confused with the roads in some parts will be set to zero since they are unchanged by γ_{Li} . However the reconstructed image S_{op} , contains a lot of details corresponding to the back ground that are confused with the roads in some parts and also bright and dark thin irregular zones .

reconstructed image

Figure 3 (c) Reconstructed image

top hat filtered image

Figure 3 (d) Sum of top hats image using ANMM

Using Differential Properties as a Separating Tool: The curvature evaluation using the Laplacian operator gets positive values on a width smaller than in the case of curvature evaluation of bright or dark thin irregular zones. The curvature evaluation is much better using adaptive openings than non adaptive operators. After computing a Laplation operation , we obtain a good estimation of the curvature. Then we perform adaptive opening and adaptive closing in multiscale from 15 to 30. Hence the sign of the Laplacian can be used as a good approximation of the direction of the curvature. The algorithm is applied for the for the aerial images of Mysore city.

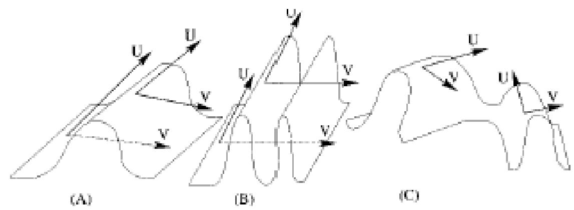

Figure 4 (a) , (b) , (c) Laplacian operator in U & V Direction

IV . Main Algorithm

$$S_{op} := \gamma^{rec}_{So} \left(\mathrm{Max}_{i=1,\ldots,12} \{\gamma_{L\,i}(s_o)\}\right)$$

$$S_{sum:} = \sum_{i=1}^{12} \left(S_{op} - \gamma_{Li}\,(S_o) \right)$$

The transformation (a sum of top hats) reduces small bright noise and improves the contrast of all linear parts. Though the roads could be manually segmented with a simple threshold on S_{sum}, since the images contain noisy data , it requires further treatment . The computation of the curvature

$S_{lap} := Lapalacian\ (Gaussian^{width=7px}_{\sigma=7/4}\ (S_{sum}))$

Then the alternating filter results in the final result

$$S_1 := \gamma^{rec}_{Slap} \left(\mathrm{Max}_{i=1,\ldots,12} \{\gamma_{L\,i}(s_{lap})\}\right)$$

$$S_2 := \phi^{rec}_{S1} \left(\mathrm{Min}_{i=1,\ldots,12} \{\phi_{L\,i}(s_1)\}\right)$$

$$S_{res} := \left(\mathrm{Max}_{i=1,\ldots,12} \{\gamma^2_{Li}\,(s_2)\} \geq 1\right)$$

The openings are adaptive opening filters and closings are adaptive closing filters using multiscale representation. The algorithm is also applied to aerial image of Houston .

IV. LIMITATIONS OF ADAPTIVE NEIGHBORHOOD MATHEMATICAL MORPHOLOGY . (ANMM)

The difficulty in using the adaptive neighbored multiscale morphology (ANMM) is computational Complexity. The Computational Complexity can be reduced by introducing a threshold, th, in our algorithm so that the differences smaller than th are ignored in the comparison with the values of x in the image x (i,j) .

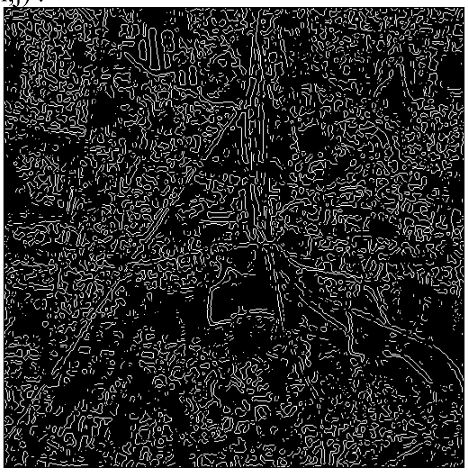

Figure 5 (a) Adaptive Edge detection

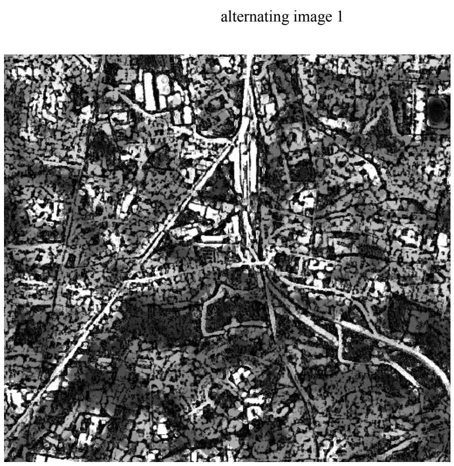

Figure 5(b) . Alternating filter1

Figure 5(c). Alternating filter2

Fig 5 . Laplacian images highlighted around zero

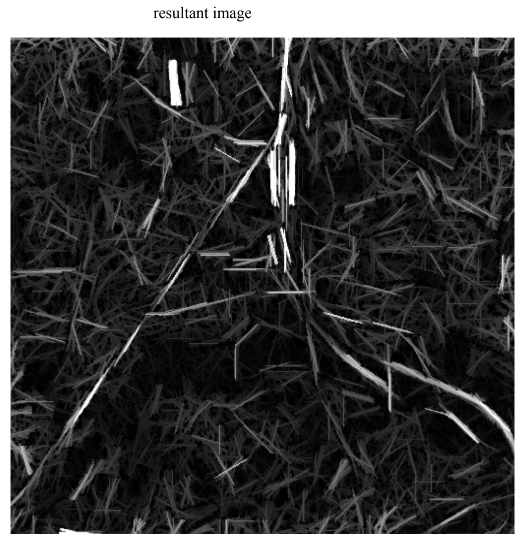

Figure 6(a) Resultant image of Adaptive Multiscale Morphology

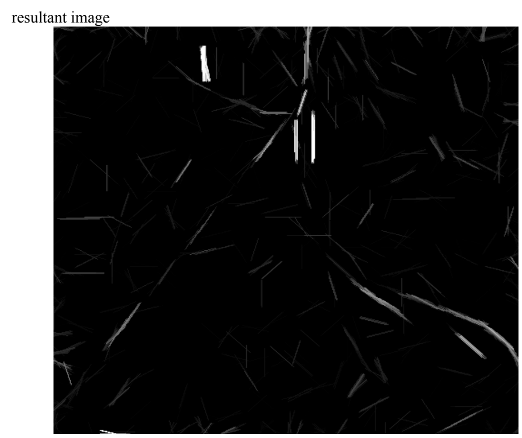

Figure 6(b) Resultant image of Non Adaptive Multiscale Morphology

Fig 6. Comparing the resultant images of ANMM method and normal one

V. RESULTS

The above algorithm using ANMM for segmenting the road pattern from the aerial images is robust and accurate . The final road images are thoroughly segmented from the background . The images of adaptive and non adaptive methods of the morphological operators are compared in fig 5(a) & 5 (b) . It is seen that the algorithm with adaptive method is retaining almost all the edges than the normal (non adaptive) method of segmentation But the sharp edges of the road side buildings and other obstacles affects the continuity of the segmented road . Hence the output image needs manual editing to get a complete skeleton of the segmented road at the output . The method suggested in [4] , is a semi–automatic approach for road extraction . Our approach in this paper is an algorithm for fully automatic approach which requires less detailed and explicit road model

Figure 7(a) Original Image of Houstan city

supremum of openings

Figure7(b) ANMM Supremum of openings

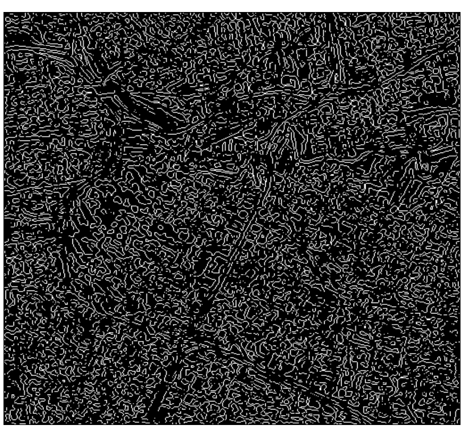

Figure7(c) ANMM Edge detection by LoG operator

resultant image

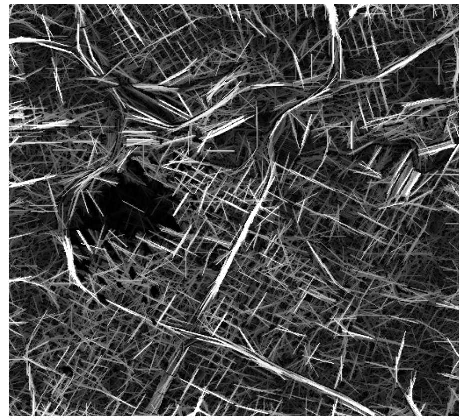

Figure7 (d) Segmented road image of Houste city on applying the ANMM algorithm

VI. CONCLUSION

The fully automatic road segmentation is robust, and accurate because of the Adaptive Neighborhood Multiscale Morphology (ANMM) Technique . The segmentation does not need any user interface as required in the semi automatic method of road extraction [1] & [2].

REFERENCES

[1] Miriam AMO , Fernando Martinez and Margarita Torre , " Road Extraction from Aerial Image using a Region Competition Algorithm ," IEEE Transactions on Image Processing , Vol . 15, No.5 , May 2006 , pp 1192 – 1201

[2] A. Baumgartner , SA. Hintz , C. Weidman , "Efficient Methods and Interfaces for Road Tracking " , Proc. PCV , Vol B , 2002 , pp 28

[3] F. Cheng & A.N. Venesanopoulous , " Adaptive Morphological filter for image processing ," IEEE transactions on Image Processing , Oct 1992 , pp 533 -539

[4] [Johan Debayle , Jean – Charles Pinoli , " Multiscale Image Filtering and Segmentation by means of Adaptive Neighborhood Mathematical Morphology " Proc. Intl . Conf. on Image Processing , Vol 3 , 11 -14, Sept . 2005 , pp 537 -450

[5] Z. Y. Jiang , X. L. Chen , Y.S. Li , C.Q. Chen, "A Multi– scale segmentation method for remotely sensed images based on granulometry" International Society for Photogrammetry and Remote Sensing ISPRS 2004

[6] Paolo Gamba and Gianni Lisini , " Improving Urban Road Extraction in High Resolution Images Exploiting Directional Filtering , Perceptual Grouping , and Simple Topological Concepts " IEEE Geoscience and Remote Sensing Letters , Vol 3 , No 3 , July 2006

[7] J.C. Pinoli and J. Debayle , " Logarithmic Adaptive Neighborhood Image Processing (LANIP): Introduction , Connections to Human Brightness Perception , and Application Issues " EURASIP Journal on Advances in Signal Processing , Volume 2007 , Article ID 36105