AN IMAGE SEGMENTATION LEVEL SET METHOD FOR BUILDING DETECTION

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ABSTRACT. In this paper the advanced method of geodesic active contours was developed for the task of building detection from aerial and satellite images. Automatic extraction of man-made structures including buildings, building blocks or roads from remote sensing data is useful for land use mapping, scene understanding, robotic navigation, image retrieval, surveillance, emergency management procedures, cadastral etc. A level set method based on a region-driven segmentation model was implemented with which building boundaries were detected, through this curve propagation technique. The essence of this approach is to optimize the position and the geometric form of the curve by measuring information along that curve, and within the regions that compose the image partition. To this end, one can consider uniform intensities inside objects and the background. Thus, given an initial position of the curve, one can determine global, region-driven functions and provide a statistical description of the inside and outside object area. The calculus of variations and a gradient descent method was used to optimize the variational functional by an iterative steady state process. Experimental results demonstrate the potential of the proposed processing scheme.

KEY WORDS: Remote sensing, feature extraction, object detection, image processing, curve evolution, variational methods, geodesic active contours, man-made objects.

1. INTRODUCTION

During the past two decades there has been a lot of research towards the automatic extraction of man-made objects from aerial and space images (Gruen et al., 1995; Gruen et al., 1997; Baltsavias et al., 2001). Efforts are concentrated, mainly, in building (Mayer H., 1999) and road network extraction (Mena J. B., 2003). Among the various methods, processing schemes and systems (automatic and semi-automatic) which have been proposed, deformable models (snakes, active contours) and curve evolution methods, in general, have given promising results.

Snakes (Kass et al., 1987) were first utilized in (Cohen, 1991) as well as in (Gruen and Li, 1997) where semi-automatic methods on linear object extraction and road extraction were, respectively, presented. Later on Zafiropoulos and Schenk (1998) tackled the problem of embedding color image information, coming from different channels in deformable models of contour type for the extraction and localization of road structures of small width. Jeon et al. (2000) used snakes to extract roads accurately. Laptev et al. (2000) also presented the snake application in cartographic object extraction. Other, recent, applications of the standard or more advanced deformable models can be found in (Agouris et al., 2001; Ruther et al., 2002; Rochery et al., 2003; Bailloeul et al., 2005).

In all above cases, the main limitation of the method was deformable model incapacity to change its topology (Paragios et al., 2005). The initial contour(s) can not split or merge. Only in cases in which the number of desired object for extraction is known, may one start with such a number of evolving contours but still, they can not split or merge and form a general processing system. Recently, the problem of the restricted curve topology was solved (Caselles et al., 1997) and moreover based in the pioneer work of Osher and Sethian (1998) was further expanded with the use of the level set method. Variational geometric level set methods are, nowadays, an established technique for various computer vision applications (Osher and Paragios, 2003).

Recently, level set method have been applyied to satellite imagery for the general image segmentation task (Samson et al., 2001; Ball and Bruce, 2005; Besbes et al., 2006). Cao et al. (2005) proposed a two-stage level set evolution scheme for man-made objects detection in aerial images. The method, which is based on a modified Mumford-Shah model, uses a coarse-to-fine strategy and a fractal error metric at the fast coarse evolution stage. Results were promising, although, only based on a visual evaluation. In this paper, level sets were applied for man-made object detection to an Ikonos one meter ground resolution panchromatic image from the Agios Stefanos area near Athens, Greece. The extraction of buildings was the main goal here and promising results are presented.

2. METHODOLOGY

2.1 Region-based geometric level set segmentation

With the advantage of being implicit, intrinsic and parameter-free, level sets track moving interfaces through either model-free (Paragios and Deriche, 2002) or either model-based (Cremers, 2003) methods.

In this paper a model-free region-driven level set technique was implemented, similar to the energy functional proposed by (Paragios and Deriche, 2002; Karantzalos and Paragios, 2005), as their segmentation results was promising. The essence of this approach is to optimize the position and the geometric form of the curve by measuring information along that curve, and within the regions that compose the image partition. To this end, one can assume without loss of generality that objects and the background are uniform.

To this end, based on a motion equation that dictates the propagation of a closed structure, one can construct a structure of a higher dimension and define a corresponding flow such that its zero level set yields always to the position of the input structure. A step further is to consider the definition of the problem and the objective function (Zhao et al., 1996) directly on the space of level set representations. For a given open region Ω with smooth boundary, it is assumed the existence of a level set function $\phi(x,y)$ which is Lipschitz continuous. Towards this end, one can define the approximations of Dirac and Heaviside (Zhao et al., 1996) distributions:

$$\delta_a(\phi)=\begin{cases}0 & , \ |\phi|<a \\ \frac{1}{2a}\left(1+\cos\left(\frac{\pi\phi}{a}\right)\right) & , \ |\phi|>a\end{cases}$$

$$H_a(\phi)=\begin{cases}1 & , \ \phi>a \\ 0 & , \ \phi<-a \\ \frac{1}{2a}\left(1+\frac{\phi}{a}+\frac{1}{\pi}\sin\left(\frac{\pi\phi}{a}\right)\right) & , \ |\phi|<a\end{cases}$$

and use them to introduce an image partitioning objective function.

Boundary attraction as well region-consistency terms can be defined based on an evolving function ϕ. The geodesic active contour (Caselles et al., 1997) can be used for example to perform boundary extraction.

$$E_{boundary}(\phi)=\underbrace{\iint_\Omega \delta_a(\phi)b(|\nabla I|)|\nabla\phi|\,d\Omega}_{boundary\ module}$$

where $b:\mathbb{R}^+\rightarrow[1,0]$ is a monotonically decreasing function. The lowest potential of this functional corresponds to a minimal length geodesic curve attracted by the boundaries of the structure of interest.

Regional/global information can improve performance of boundary-based flows (Paragios and Deriche, 2002) that suffer of being sensitive to the initial conditions. The central idea behind a region-driven functional is to use the evolving interface to define an image partition that is optimal with respect to some grouping criterion. Within the level set representation such partition is natural according to the sign of the embedding function. The Heaviside function can be considered to define such partition:

$$E_{region}(\phi)=\iint_\Omega\left[H_a(\phi)\cdot r_{in}(I)\right]d\Omega+\iint_\Omega\left[\left(1-H_a(\phi)\right)\cdot r_{out}(I)\right]d\Omega$$

according to some region descriptor functions $r_{in}:\mathbb{R}^+\rightarrow[1,0]$, $r_{out}:\mathbb{R}^+\rightarrow[1,0]$ that are monotonically decreasing functions like:

$r_{in}(I)=\frac{(\mu_{in}-I)^2}{\sigma_{in}^2}$, μ_{in} : mean of the inside object's area, σ_{in} : covariance of the inside object's area

$r_{out}(I)=\frac{(\mu_{out}-I)^2}{\sigma_{out}^2}$, μ_{out} :mean of the background, σ_{out} : covariance of the background

Such descriptors measure the quality of matching between the observed image and the expected regional properties of the structure of interest and the background.

Integration of the boundary and the region-driven term can be considered to perform segmentation (Paragios and Deriche, 2002), namely the geodesic active region model. In the absence of noise, occlusions and corrupted visual information, such method can deal with local deformations. On the other hand, it cannot account for prior shape knowledge, deal with noisy, corrupted and occluded data.

2.2 Building detection processing scheme

The above described curve evolution level set functional was implemented and tested for the detection of building from an IKONOS PAN image. Before the application of the level set segmentation a pre-processing step for image enhancement and smoothing took place. The applied pre-processing algorithms were described in Karantzalos and Argialas (2006). The pre-processed image was the input to the curve evolution energy and the resulting segmented image was obtained. Finally, certain statistics were calculated for each of the detected segments implying possible buildings: area, perimeter, shape complexity, eccentricity, and orientation. Depending on the above, mainly geometric and shape characteristics, segments that are assumed not to be building were eliminated and thus the final detected buildings were extracted.

3. RESULTS AND DISCUSSION

The developed scheme has been applied to an IKONOS PAN one meter ground resolution image, from the Agios Stefanos area near Athens, Greece.

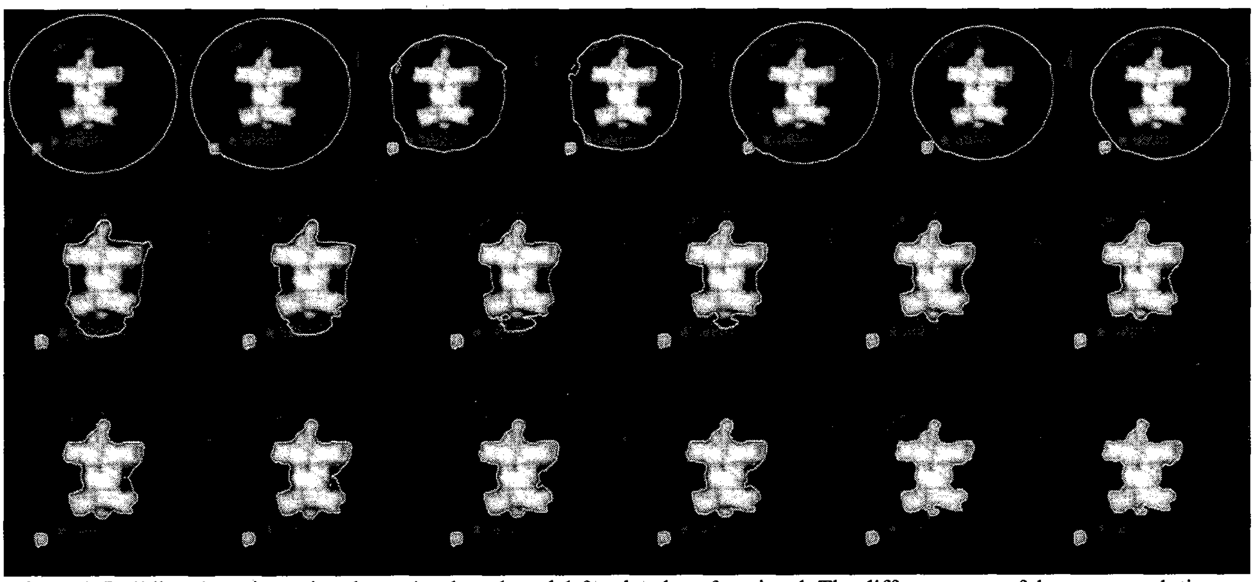

Figure 1. Building detection using the region-based model-free level set functional. The different steps of the curve evolution propagation are shown, starting from an initial arbitrary elliptical curve leading to the final detected two buildings boundaries.

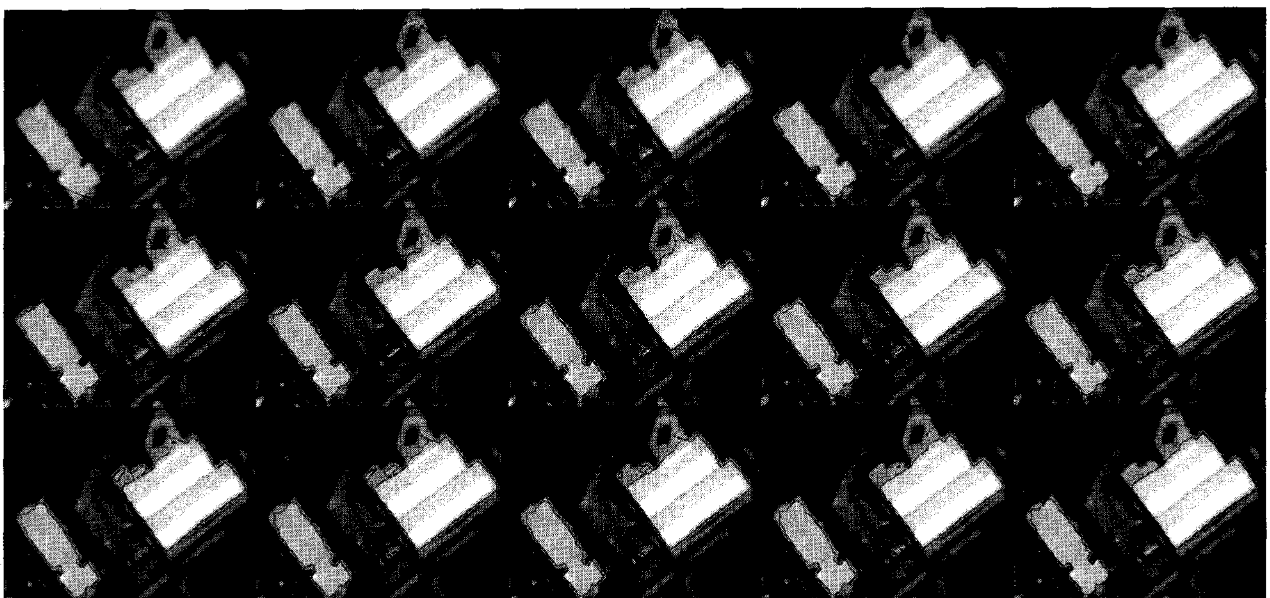

Figure 2. Building detection using the region-based model-free level set functional. The different steps of the curve evolution propagation are shown, starting from an initial arbitrary elliptical curve leading to the final detected two buildings boundaries.

In figure 1 and 2 two different buildings were detected. In both cases the level set curve evolution energy functional managed to successfully extract the building boundaries. The selected level set states from the curve evolution propagation, which are shown in both figures, demonstrate the way that the level set is successfully approximating each building's boundaries.

The evaluation of the results was done visually. However, buildings are detected in real time (approximately 2sec. is the computation time for each image in a moderate Pentium IV home computer) and with an efficient detected boundaries precision. Note that here the main goal was to investigate level set curve evolution model performance for the building detection task and its theoretical superior performance against the classical and more advanced active contours. In both figures the initial elliptical curve is splitting in two, three or four curves and at the end of the minimization stage has managed successfully to detect the two buildings that appear in the images.

Furthermore, level sets have been extensively used for tracking of moving objects in numerous computer vision applications (Karantzalos and Paragios, 2005; Paragios et al., 2005). In the same way, apart from the detection of the buildings in a single image, level sets can be used for change detection purposes and the update of maps. The initial curve can be derived from the previous knowledge about building boundaries and then based on a more recent image the curve can propagate and detect new buildings or changes that have been made.

4. CONCLUSIONS & FUTURE PERSPECTIVES

Experimental results showed that level sets can effectively be used for building detection tasks from remote sensing imagery. The developed scheme's detection accuracy is currently under qualitative and quantitative evaluation with ground truth data.

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References

Agouris P., Gyftakis S., Stefanidis A., 2001a. Dynamic Node Distribution in Adaptive Snakes for Road Extraction, Vision Interface 2001, pp. 134-140, Ottawa, Canada.

Bailloeul T., Prinet V., Serra B., Marthon P., Chen P. and Zhang H., 2005. Urban building land use change mapping from high resolution satellite imagery, active contours and Hough voting, ISPMSRS, Beijing, China.

Ball, J. E., L. M. Bruce. 2005. Level Set Segmentation of Remotely Sensed Hyperspectral Images. Proceedings of the IEEE Geoscience and Remote Sensing Symposium. CDRom. 5638 - 564.

Baltsavias E.P., Gruen A., VanGool L., 2001. Automatic Extraction of Man-made Objects from Aerial and Satellite Images III, Taylor & Francis, 425p.

Besbes, O., Belhadj, Z., Boujemaa, N., 2006. Adaptive Satellite Images Segmentation by Level Set Multiregion Competition, INRIA, Research Report-5855.

Cao Guo, Yang Xin, Mao Zhihong, 2005. A Two-Stage Level Set Evolution Scheme for Man-Made Objects Detection in Aerial Images. CVPR (1): 474-479.

Caselles V., Kimmel R., and Sapiro G., 1997. Geodesic Active Contours. IJCV, 22:61–79.

Cohen, L.D., 1991. On active contour models and balloons. CVGIP Image Understand. 53, 211–218.

Cremers. D., 2003. A Variational Framework for Image Segmentation Combining Motion Estimation and Shape Regularization. In IEEE CVPR, pages 53–58.

Gruen, A., E. Baltsavias, and O. Henricsson, 1997. Automatic Extraction of Man-Made Objects from Aerial and Space Images. Birkhaeuser, Basel.

Gruen, A., Li, H., 1997. Semi-automatic linear feature extraction by dynamic programming and LSB-Snakes. Photogrammet. Eng. Remote Sensing 63, 985–995.

Gruen, A., O. Kuebler, and P. Agouris, 1995. Automatic Extraction of Man-Made Objects from Aerial and Space Images. Birkhaeuser, Basel.

Jeon, B.K., Jang, J.H., Hong, K.S, 2002. Road detection in spaceborne SAR images using a genetic algorithm. IEEE Trans. Geosci. Remote Sensing 40 (1).

Karantzalos K . and Argialas D., (to be published in 2006) "Improving edge detection and watershed segmentation with anisotropic diffusion and morphological levelings", *International Journal of Remote Sensing.*

Karantzalos K. and N. Paragios, 2005. Implicit free-form-deformations for multi-frame segmentation and tracking, IEEE VLSM-ICCV05, China.

Kass, M., Witkin, A., Terzopoulos, D., 1987. Snakes: Active contour models. Internat. J. Comput. Vis., 321–331.

Laptev, I., Mayer, H., Lindeberg, T., Eckstein, W., Steger, C., Baumgartner, A., 2000. Automatic extraction of roads from aerial images based on scale space and snakes. Machine Vision Applicat. 12 (1), 23–31.

Li, H., 1997. Semi-automatic road extraction from satellite and aerial images. Ph.D. Thesis, Report no. 61, Institute of Geodesy and Photogrammetry, ETH-Zurich, Switzerland.

Mayer H., 1999. Automatic Object Extraction from Aerial Imagery—A Survey Focusing on Buildings, Computer Vision and Image Understanding, Volume 74, Issue 2, 1 May 1999, pp.138-149

Mena J. B., 2003. State of the art on automatic road extraction for GIS update: a novel classification, Pattern Recognition Letters, Volume 24, Issue 16, pp 3037-3058.

Osher S. and Paragios N., 2003. Geometric Level Set Methods in Imaging Vision and Graphics, Springer Verlag, ISBN 0387954880.

Osher S. and Sethian J., 1988. Fronts propagation with curvature dependent speed: Algorithms based on Hamilton-Jacobi formulations, *J. Comput. Physics*, vol. 79, pp. 12–49.

Paragios N. and Deriche R., 2000. Geodesic Active Contours and Level Sets for the Detection and Tracking of Moving Objects. IEEE Transactions on Pattern Analysis and Machine Intelligence, 22:266–280,.

Paragios N. and Deriche R., 2002. Geodesic Active Regions: A New Framework to Deal with Frame Partition Problems in Computer Vision, Journal of Visual Communication and Image Representation, vol. 13, pp. 249–268.

Paragios N., Chen Y. & Faugeras O., 2005. Handbook of Mathematical Models of Computer Vision, Springer, ISBN 0387263713.

Rochery M., Jermyn I. H., and Zerubia J.. 2003. Higher order active contours and their application to the detection of line networks in satellite imagery. In Proceedings of the IEEE VLSM / ICCV03, Nice, France.

Ruther, H., Martine, H.M., Mtalo, E.G., 2002. Application of snakes and dynamic programming optimisation technique in modeling of buildings in informal settlement areas. ISPRS J. Photogrammet. Remote Sensing 56 (4), 269–282.

Samson, C , Blanc-Feraud, L , Aubert, G , and Zerubia, J , 2001. Two variational models for multispectral image classification," Energy Minimization Methods in Computer Vision and Pattern Recognition, Lecture Notes in Computer Science, vol. 2134 , pp. 344 -356.

Zafiropoulos, P., Schenk, T.F., 1998. Extraction of road structures with color energy models. In: Sabry, F., El-Hakim, Gruen, A. (Eds.), Videome-TRICS VI., Proc. SPIE, vol. 3641, pp. 276–290.

Zhao H-K., Chan T., Merriman B., and Osher S., 1996. A variational Level Set Approach to Multiphase Motion. Journal of Computational Physics, 127:179–195.