Semi Automatic Building Segmentation using Balloons from 1m Resolution Aerial Images

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Abstract

This paper proposes a new building segmentation method from 1m resolution imagery using an Active Contour Model, known as "Balloons". The original balloons, which was designed by Cohen(Cohen, 1991) to extract features from medical images, are modified for building segmentation. The proposed method consists of two phases. Firstly, building boundaries are extracted by balloons with a given position on buildings from an operator. Since balloons actively adjust their shapes according to the boundaries, there is no more shape limitations on detecting buildings. Secondly, buildings are segmented by connecting the corners detected from the building boundaries, because most buildings, which are man-made objects, are effectively described by polygons. The test results show that most buildings are segmented efficiently and easily. The proposed method is new and timely as 1m resolution spaceborne imagery will be available in the very near future. The proposed method can be used for operational building segmentation from such imagery.

1. Introduction

The emergence of high resolution (1m) spaceborne imagery has made urban mapping from space possible and building segmentation is one of the key elements for such urban mapping. There are several methods proposed for building segmentation but mostly for aerial imagery at sub-meter resolution. However, the authors would like to emphasize that image resolution is one of the essential factors to determine scene characteristics and any image understanding process has a particular range of image resolution for operation. In particular, building segmentation from urban images at 1m resolution is the most difficult, since such images contain a lot of small buildings with weak edges. Therefore, it is necessary to develop building segmentation methods for 1m resolution imagery.

A graph-based automatic building segmentation system has been developed (Kim and Muller, 1995) for aerial imagery at sub-meter resolution. This system has been tested with various urban and suburban images at sub-meter resolution and shown good performance. However, experiments with 1m resolution imagery have indicated that this system needs modification (Muller et al., 1997).

One of the possible approaches is using deformed models to extract features of interest in images. Kass et al.(Kass et al., 1988) introduced an energy-minimizing spline, known as "Snakes", guided by external constraint forces and influenced by image forces that pull the spline toward features such as lines and edges. Since snakes change their shapes dynamically to lock onto nearby edges localizing themselves accurately, they are referred to as active contour models. Cohen(Cohen, 1991) proposed another active contour model, known as "Balloons", which was a modified model of snakes. In this model, which was applied to medical images, an inflation force term was added to make a balloon grow from initial position to extract interesting regions.

In this paper, we propose a new building segmentation method from 1m resolution imagery using balloons. Since the original balloons were designed for medical images, these have been modified accordingly. Buildings are segmented through two steps.

1) *Extract building boundaries by balloons.* Starting from initial position, balloons grow to the boundaries. By this method, building boundaries are extracted without limitations on the shapes of buildings.
2) *Connect corners detected from the boundaries*, since the shapes of most buildings are polygon but the boundaries extracted by balloons are smooth for their internal energy.

The main theory of "balloons" is reviewed in the next section. The following section describes the application of balloons to 1m resolution aerial images for building boundary extraction. In Section 4, we present a method on how to detect corners from a boundary. We illustrate the performance of proposed method for building segmentation from 1m resolution images. Due to the difficult access to real 1m resolution spaceborne images, the proposed method has been tested on 1m resolution aerial images. Original images at 5cm resolution are re-sampled and interpolated to make 1m resolution images. Finally, in Section 5, we discuss necessary improvements required and directions of our future work.

2. Balloons: Active Contour Model (Cohen, 1988)

Balloons are energy minimizing curves. A functional E, which represents the energy of a balloon, is defined as

$$E_{BALLOON} = \int_0^1 \left[w_1 |\mathbf{v}'(s)|^2 + w_2 |\mathbf{v}''(s)|^2 + E_{ext}(\mathbf{v}(s)) \right] ds$$
$$\mathbf{v}(s) = (x(s), y(s)),$$

where the primes denote differentiation, E_{ext} is the potential energy associated to external forces, and $\mathbf{v}(s)$ represents the position of a balloon parametrically. The external forces can be designed according to the desired goal; if we extract edge points, the external forces should depend on the gradient of the image. The first two terms of the functional E form the energy by the internal forces. The choice of weights w_i determines the elasticity and rigidity of balloons. The larger the elasticity is, the more detail parts are extracted. The rigidity controls how easily balloons are bent, therefore if the rigidity is large, balloons would be blocked by weak edges. Thus balloons are affected by the internal forces which impose the smoothness of balloons and the external forces which push balloons to the interesting features.

If v is a local minimum for E, it satisfies the following Euler-Lagrange equation:

$$-(w_1 v')' + (w_2 v'')'' + \nabla E_{ext} = 0. \qquad (1)$$

In this equation, the external force is

$$\nabla E_{ext} = -k_1 \mathbf{n}(s) + k \frac{\nabla P}{|\nabla P|}$$
$$P = -|\nabla I(\mathbf{v}(s))|^2,$$

where I denotes the image intensity and $\mathbf{n}(s)$ is the outward normal vector to the curve at point $\mathbf{v}(s)$. The first term of the external force is inflation force. The inflation force makes balloons grow until they lock on boundaries.

3. Application of balloons

In our proposed method, buildings are segmented as follows:

- Extract building boundaries by balloons.

- Detect corners from the boundaries.
- Connect corners to represent buildings by polygons.

Fig. 1. Test image

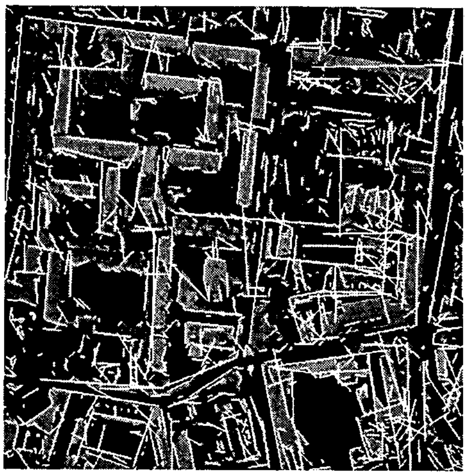

Fig. 2. Test result

Since 1m resolution aerial images contain many small buildings with weak edges and lots of noises inside building boundaries, balloons which are pulled by the gradient of the image cannot successfully extract boundaries. In our proposed method, a line functional to the external forces is added to attract and block balloons.

Usually line extraction from high resolution images consists of edge detection, edge linking, line detection, and line merging. We tested line extraction on 1m resolution aerial images. Fig. 1 is a test image and Fig. 2 is the test result. We found out the usual method was not sufficient for 1m resolution images due to several reasons:

- Many parts of weak edges cannot be detected. Edge linking does not work well since edge orientations of weak edges change abruptly.
- Lines are detected as several segments. This results in increasing error of merging lines.
- Gaps between buildings are very small. Therefore, some lines from adjacent buildings are merged together.

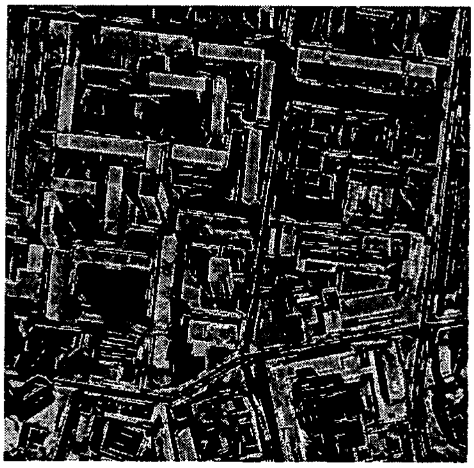

Fig. 3. Line extraction from 1m resolution aerial image

For better line extraction, we use the framework of Burns et al.(Burns et al., 1986). Further details can be found in the reference. By the proposed method, lines are extracted as follows:

1) *Group pixels into line-support regions* based on similarity of gradient orientation. This allows data-directed organization of edge contexts without commitment to masks of a particular size.
2) *Approximate the intensity surface by a planar surface.* The planar fit is weighted by gradient magnitude associated with pixels so that intensities in the steepest part of an edge will dominate.
3) *Extract attributes from a line-support region and a planar fit.* The attributes extracted include a representative line and its length, contrast, width, location, orientation, and straightness.

A result by this method is shown in Fig. 3. We exclude lines whose length is below 10 pixels. This line information is used as a line functional in the proposed balloon model.

To extract building boundaries using balloons, initial positions should be given. In our method, coordinates of a point inside each building are given by an operator. Fig. 4 shows boundaries detected by our method and Fig. 5 is the boundaries superimposed on the test image. As shown in the figure, without limitations on the shapes of buildings, the boundaries of most of the significant buildings are detected with little effort. But some buildings with lots of noises or with low image intensities are not detected, because the edges are too weak to extract lines and there are no image forces which guide balloons to the boundaries. One possible solution is to generate building hypotheses with the line information. For example, if parallelogram is considered, virtual lines would be added. The building hypotheses will act as another external force to make balloons lock onto boundaries of such buildings.

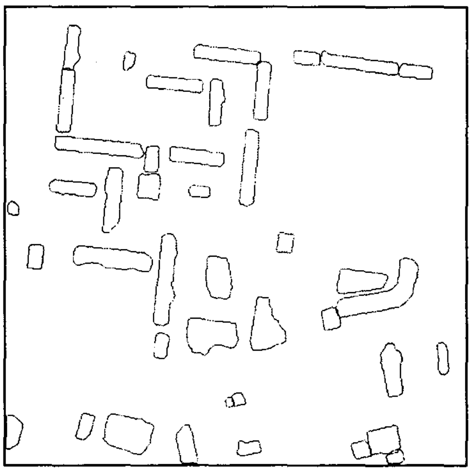

Fig. 4. Boundaries detected by balloons

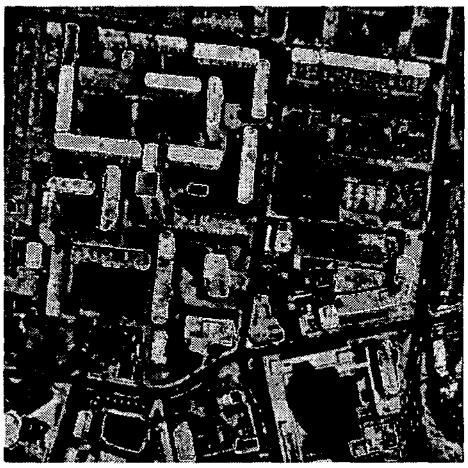

Fig. 5. Boundaries superimposed on the test image

4. Corner detection

As show in Fig. 4 and 5, the boundaries are smooth. But buildings are generally represented by polygons, we should detect corners of buildings and connect them. We define a corner as a point where the angle changes very abruptly. Angle changes are calculated as follows:

$$\theta_i' = \frac{\Delta\theta_i}{2h} \quad \theta_i'' = \frac{\Delta\theta_i'}{2h}$$
$$\Delta\theta_i = \theta_{i+1} - \theta_{i-1}$$
$$\Delta\theta_i' = \theta_{i+1}' - \theta_{i-1}',$$

where θ_i denotes an angle of the i-th point and h denotes space step. In our experiments, we regard a point where the first and the second derivative of θ_i is over 10 and 3, respectively, as a corner. By changing the thresholds, sharp corners or smooth corners can be detected. Detected corners are shown in Fig. 6 and superimposed on the test image in Fig. 7. As shown in Fig 6 and 7, most corners are located accurately. However, some corners of buildings, which are supposed to be one, are detected as several adjacent corners. Therefore, merging detected corners by analysis and adjusting positions may be needed. After detecting the corners, we finally make building descriptions by connecting them. Since segmented buildings are described by polygons, the information storage is small and the information can be used at establishing GIS effectively. Fig. 8 shows the buildings segmented by our method.

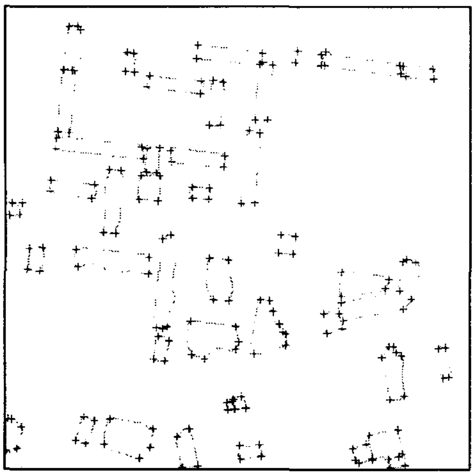

Fig. 6. Detecteds corner from the boundaries

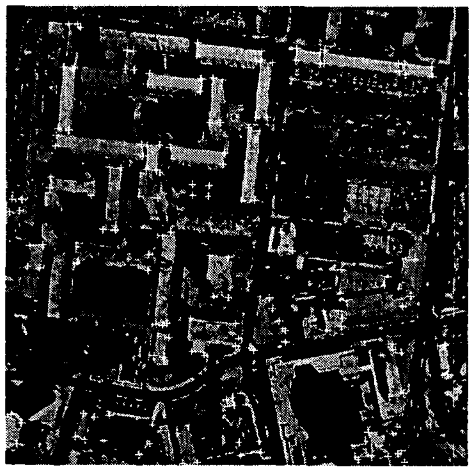

Fig. 7. Corners superimposed on the test image

Fig. 8. The result of building segmentation

5. Conclusion

In this paper we addressed the problems in application of building segmentation method for 1m resolution images and presented a new building segmentation method from such images. We modified the original balloons, which were applied to medical images, to apply to aerial images, which have lots of strong noises, by adding line functional to external forces. This enables balloons to be attracted and blocked by building boundaries. Because balloons are active contour model, there is no limitation on the shapes of detected boundaries. However, since the detected boundaries are smooth for the nature of balloons, after detecting building boundaries by balloons with given initial positions, building descriptions are established by connecting corners detected from the boundaries. As shown from the result, most of significant buildings are segmented except some buildings with weak edges and low intensities. These buildings cannot be detected by balloons, because the potential energy resulted from the edges are low enough to be regarded as noises and there is no significant changes in edge gradients of buildings with low intensities. One of the possible ways to solve the problem is generating building hypotheses from line information by using the knowledge about the shapes of general buildings like parallelogram and using them as another external force.

We believe that operator's interaction is inevitable in building segmentation from 1m resolution images, therefore, our proposed method is new and timely as 1m resolution spaceborne imagey will be available in the near future.

Acknowledgements

The work presented here is supported by Ministry of Science and Technology of the Government of Korea(Contract No. NN20560). The authors appreciate Wonkyu Park and Dongseok Shin's contribution of their ideas and discussions on detecting building boundaries from images.

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