Building Roof Contours Extraction from Aerial Imagery Based On Snakes and Dynamic Programming

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SUMMARY

This paper presents a method for building roof contours extraction from high-resolution aerial imagery taken over complex urban scenes. The proposed method is based on the optimization of a snakes energy function that represents building roof contours in the image-space digital reference system by using the dynamic programming technique. Formally, snakes (or active contour models) are parametric curves defined in the image domain. Snakes were proposed in the late 1980s and since then they have been very noticeable as one of the most active and successful research topic in image segmentation, and they have been largely employed in image analysis tasks like boundary tracking, shape modeling, and feature extraction. The snakes' position on an image is defined by its energy, which is given by a summation of internal and external energy terms. The internal energy is related to the intrinsic characteristics of the curve that is calculated from the point coordinates defining the curve on the image. External energy, on the other hand, is calculated from image data based on well-defined properties of the object of interest. External energy allows the snakes curve to move towards the object boundary. So, a snake model is able to incorporate different information concerning the desired objects according to the specific application. For the proposed method in this paper, the external energy for the energy function that represents building roof contours uses magnitude for edge points (i.e. a set of points that defines a building roof contour on the aerial image). The energy function is solved by using the dynamic programming algorithm, which is a quite suitable optimization procedure when not all model variables are inter-related simultaneously. In such case, the original mathematical model can be written as a summation of sub-functions depending only on a few model variables. The dynamic programming algorithm advantage (compared to other procedures) is its reduced number of required operations to get the optimal solution (find a set of optimal variables) for the energy function. Furthermore, the dynamic programming algorithm allows imposing constraints to the functional model variables, in such a way that only constrained variables will be selected. As most of the building roof contours are defined by regular polygons, constraints were applied to the energy function to enforce the snakes curve to develop corners on building roof contour corners. Experimental evaluation was carried out using aerial imagery and the obtained results showed the potentiality of the proposed method for extracting building roof contours.

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1. INTRODUCTION

Feature extraction from digital imagery is an active research field since the 1970s. In this context, digital remote sensing imagery has been widely used as input data for developing of new semi- and fully-automated feature extraction methods. In this sense, snakes and dynamic programming have been widely applied for image analysis tasks as feature extraction, as well as shape modeling, segmentation, and boundary tracking. These concepts have been widely used to develop new methods to extract objects as buildings and roads from multi-resolution remote sensing images. These features are basic for many mapping applications, e.g., GIS building and maintenance, urban modeling, surface representation, and telecommunications. For example, Gruen & Li (1995) and Dal Poz & Vale (2003) used approaches based on dynamic programming for semi-automated road extraction from medium- and high-resolution remote sensing images. Regarding to snakes, two examples of approaches for road and building extraction can respectively be found at Agouris et al. (2001) and Peng et al. (2005).

The combination of snakes and dynamic programming was already explored by Rüther et al. (2002) to extract buildings in informal settlement areas present in urban scenes of aerial images. In such approach, snakes were applied to build a feature model represent building roof contours within the image. So, the resulting model is optimized by using the dynamic programming technique, in order to provide the desired features.

In this paper, a method for building roof contour extraction from digital high-resolution aerial imagery is proposed. This method uses snakes (or active contour models) as a base for a building roof contour model formulation, which is solved by using the dynamic programming optimization technique. The final results are polygons representing the building roof contours within the image. The main difference between this and the method proposed by Rüther et al. (2002) is this method a semi-automated one and it is a result of a wider research that is still being developed as a Ph.D. thesis.

This paper is organized as follows: Section 2 presents the basic concepts of snakes and dynamic programming, as well as an overview of the proposed method. An experimental evaluation and a preliminary analysis of the obtained results are presented on section 3. Finally, some conclusions and recommendations for future work are given on section 4.

2. METHODOLOGY

Feature extraction from digital imagery is a procedure that can be formulated as an optimization problem, which can be solved by optimization techniques like dynamic programming. So, it is convenient for this purpose to implement a generic mathematical model that will represent the feature of interest to be extracted from the image and, thus, to reduce the search space (the domain of the function to be optimized).

In this paper, snakes are used as a basic function for modeling a building roof contour in the image-space domain. Then, the resulting model is optimized by using the dynamic programming technique, in order to extract polygons representing building roof outlines within aerial images that are used as input data for the proposed method.

Figure 1 depicts the flowchart for the proposed method. A digital aerial imagery is used as input data. Then, the extraction process is started up by a human operator, which supplies an approximate polygon for the building roof contour to be extracted. After that, the extraction process is performed and polygons describing the building roof contours are obtained as results. The following topics present the basic concepts of snakes and dynamic programming, as well as an overview of the method proposed in this paper.

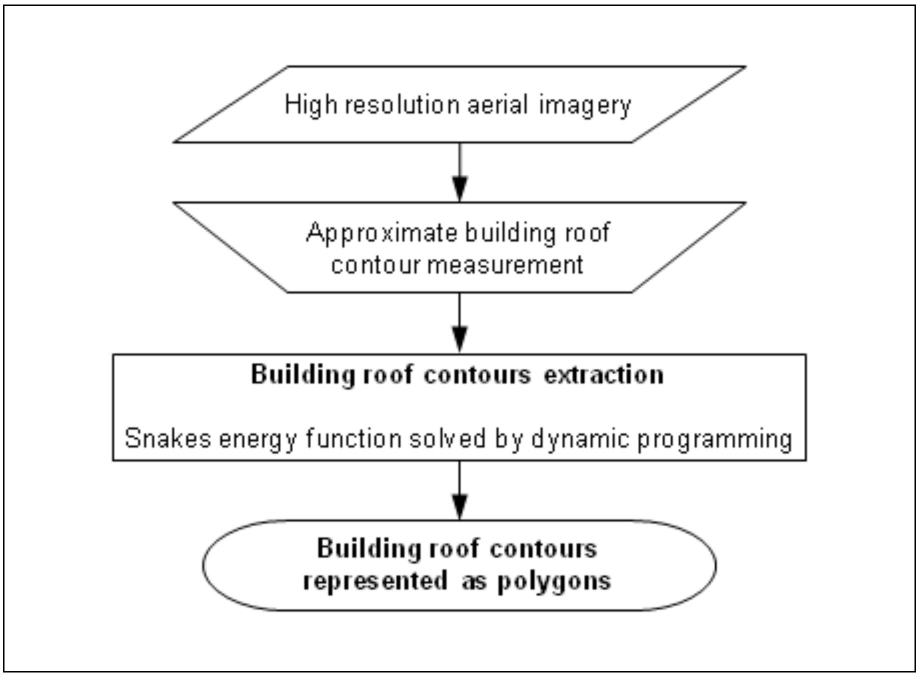

Figure 1 – Method flowchart.

2.1 Snakes

Snakes are curves defined within an image domain that move towards x and y directions by influence of internal and external forces (Xu & Prince, 1998). Snakes, also known as active contour models, are given by parametric vector functions as

$$v(s) = \left(x(s), y(s) \right), \quad \textbf{(1)}$$

in which: $x(s)$ and $y(s)$ are functions parameterized by s; $s \in [0, L] \subset \mathbb{R}^2$ is an arc-length along the snake. The closed interval $s \in [0, L] \subset \mathbb{R}^2$ is the snakes' domain, and L is the total length of the curve.

Since they were proposed by Kass et al. (1988), snakes have been widely used in applications such as image segmentation, shape modeling, and boundary tracking. Snakes' properties as shape and position (within an image) are defined by its total energy, which is given by a function:

$$E(v(s)) = \int_0^L \left(w_1(s)\left|\frac{dv}{ds}\right|^2 + w_2(s)\left|\frac{d^2v}{ds^2}\right|^2 \right) ds + E_e(v(s)), \quad \textbf{(2)}$$

in which the first equation term is the internal energy (based on the snakes' configuration) and $E_e(v)$ is the external energy of the snake, which is computed from image data and depends on the feature of interest to be extracted from the image. This term function is based on well-known properties of that object. Hence, snakes are able to incorporate different information about image objects, which varies according to the desired application.

In the Equation 2, $v_s(s)$ represents the elasticity of the curve and $v_{ss}(s)$ represents its rigidity. Those derivatives are controlled by the weighted functions $w_1(s)$ and $w_2(s)$, respectively, which are used to insert specific discontinuities into the curves.

For implementation purposes, it is convenient to represent a snake by a poly-line defined by a set of n vertices, as follows:

$$v_i = v(s_i) = (x(s_i), y(s_i)), \quad i = 0, 1, \ldots, n-1. \quad \textbf{(3)}$$

The discrete version of the snakes' energy function (Equation 2) can be represented by using finite differences to approximate the derivatives that define its internal energy function and const values α_i and β_i as the weighted functions $w_1(s)$ and $w_2(s)$, respectively. Thus, Equation 2 can be written as:

$$E(v) = \sum_{i=0}^{n-1} \left(\alpha_i \left| v_{i+1} - v_i \right|^2 + \beta_i \left| v_{i+2} - 2v_{i+1} + v_i \right|^2 \right) + E_e(v_i). \quad \textbf{(4)}$$

2.2 Dynamic programming

According to Ballard & Brown (1982), dynamic programming is an optimization technique used to solve problems when not all variables are simultaneously interrelated. It comprises a strategy based on decision-making process, which is defined as a recursive search algorithm.

Dynamic programming is a suitable optimization technique when the problem can be expressed as a function with similar structure to:

$$h(x_1, x_2, x_3, x_4) = h_1(x_1, x_2) + h_2(x_2, x_3) + h_3(x_3, x_4). \quad \textbf{(5)}$$

A classical dynamic programming problem also can be formulated as a graph search algorithm. The basic idea is sequentially finding the optimal path between the graph's nodes *A* and *N*, as depicted by the **Figure 2**.

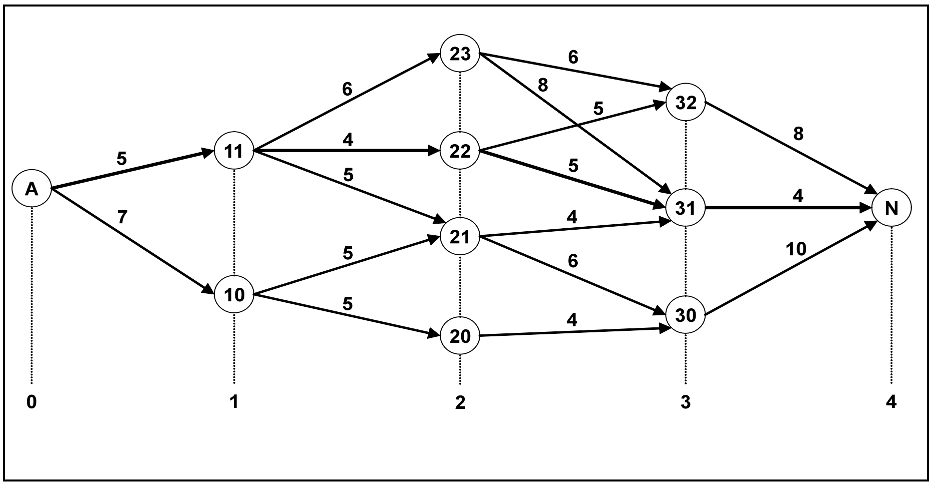

Figure 2 – Classical dynamic programming problem.

According to Gruen & Li (1995), dynamic programming technique has the following properties:

1. **Numerical stability:** The global optimal function value is always found;
2. **Optimization guarantee:** A set of best variables values is always found, since all choices are considered by the algorithm;
3. **Direct execution:** The algorithm processing is performed in a single iteration;
4. **Flexibility:** Constraints can be directly imposed on the solution into the algorithm framework.

More details about dynamic programming technique can be found in Ballard & Brown (1982) and Gruen & Li (1995).

2.3 Building roof contour model

According to Rüther et al. (2002), a generic mathematical model to represent a feature of interest to be extracted from an image can be formulated by using well know properties of that object. On the other hand, such properties can be expressed as snakes' external energy functions.

For building roof contours, edges are generally continue and well defined within an aerial image. A (discrete) external energy function for a building roof edge can be expressed as:

$$E_{edge}(v) = \sum_{i=0}^{n-1} B_i \left|\nabla G(x_i, y_i)\right|^2, \qquad (6)$$

in which B_i are negative constants and $\nabla G(x_i, y_i)$ are the gradient magnitudes for edge points (generally computed from the image intensity channel by using edge operators as, e.g., Sobel or Canny).

So, a building roof contour model based on snakes can be formulated by replacing the term $E_{ext}(v)$ into the Equation 4 by the Equation 6, which results in the following energy function:

$$E(v) = \sum_{i=0}^{n-1} \left(\alpha_i \left|v_{i+1} - v_i\right|^2 + \beta_i \left|v_{i+2} - 2v_{i+1} + v_i\right|^2 + B_i \left|\nabla G(x_i, y_i)\right|^2 \right), \qquad (7)$$

where

$$\left|v_{i+1} - v_i\right|^2 = (x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 \qquad (8)$$

and

$$\left|v_{i+2} - 2v_{i+1} + v_i\right|^2 = (x_{i+2} - 2x_{i+1} + x_i)^2 + (y_{i+2} - 2y_{i+1} + y_i)^2 . \qquad (9)$$

The Equation 7 can be written as a summation of sub-functions E_i that depends each one of only three vertices, as follows:

$$E(v) = \sum_{i=0}^{n-1} E_i(v_i, v_{i+1}, v_{i+2}). \qquad (10)$$

2.4 Optimization strategy

The Equation 10 shows a structure in which only three vertices are simultaneously interrelated, what suggests using the dynamic programming as a convenient technique for its optimization.

To start up the extraction procedure, the human operator provides an approximate polygon describing the building roof contour to be extracted within the image. This operation is performed since the snakes' model requires an initial curve for any object to be tracked. The optimization process is based upon two main steps, which are described below:

- **Contour vertices sampling:** In this step, new edge points are sampled by using information derived from the set of edge points optimized in a previous iteration. At the beginning of the extraction procedure, this set defines the approximate polygon provided by the human operator;
- **Optimization of the goal function:** In this step, the dynamic programming technique is applied to select the best set of edge points currently describing a building roof contour. These points are chosen so that a minimum energy value for the goal function will result.

These steps are sequentially repeated until the goal function is minimized, that is, no more vertices are added to the current building roof contour. Thereafter the extraction process, the extracted building roof contour is superimposed onto the image for visual checking.

3. EXPERIMENTAL EVALUATION

An experimental evaluation of the proposed method was performed using high-resolution aerial imagery data. These data consist of some image patches that were cropped from a digitized analog aerial photograph taken from a complex urban scene.

Since the chosen image was quite affected by noise, and also because snakes are widely influenced by noise within an image, a noise suppression procedure was previously applied to the evaluated image in order to improve the quality of the results provided by our building roof contours extraction method. This was done by using a simple median filter with radius 2.

Figures below show some image patches with building roof contours extracted by using the method described in this paper.

Figure 3 – Results for building roof contours extraction.

Figure 4 – Results for building roof contours extraction.

Figure 5 – Results for building roof contours extraction.

A simple visual checking on the results suggested that the method worked with a reasonable performance, since most of the extracted contours correspond to real building outlines within the image. Some of the results (examples showed on the **Figure 3**) were affected by false edges caused by shadow occurrence within the image. Sometimes those edges produce stronger responses than real building edges. As the snakes external energy term (which cause snakes to move towards edge objects) in our building roof contour model is based on gradient edge magnitude, false edges that produce stronger responses than real building edges can result in wrong convergence. Also, edges that produce weak responses decrease the quality of the results, since basic snakes are unable to converge correctly to weak edges (in most of cases).

4. CONCLUSIONS

From a visual checking of the obtained results it was possible to conclude that the proposed method worked with a reasonable performance on extracting different building roof contours from an aerial image. It can also be concluded that snakes are flexible models for feature modeling and extraction, but they are mainly affected by the image quality. On the other hand, the usage of dynamic programming provided an increasing of seed convergence, since it is a fast and robust optimization technique.

For future work, we intend to implement a numerical analysis, in order to evaluate the method's performance in a more realistic way. This analysis will be based on the estimation of quality numeric indicators, which are calculated from extracted and reference building roof contours. We also want to enhance the external energy term of our building roof contour model to improve the quality of the results given by our method. Finally, the method's performance will be evaluated on extracting more complex building roof contours, such as concave shape building roof contours.

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BIOGRAPHICAL NOTES

Antonio Juliano Fazan has received his Dipl. Eng. from the Univ. Estadual Paulista (Brazil) in 2004, and his M. Sc. degree from Univ. Estadual Paulista in 2007. Currently, he is working on to obtain his Ph.D. degree in Cartographic Sciences at the Univ. Estadual Paulista.

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