SEMI-AUTOMATIC BUILDING EXTRACTION UTILIZING QUICKBIRD IMAGERY

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ABSTRACT:

Extraction of geospatial data from digital images is one of the most complex and challenging tasks faced by computer vision and photogrammetry communities. Geospatial data and buildings in particular are required for varieties of applications such as urban planning, creation of GIS databases, and urban city models. For decades, extraction of geospatial data in urban areas has been by conventional photogrammetry using aerial photos. This method is expensive, manually operated and require well-trained personnel. In recent years we have experienced the emergence of high-resolution space borne images, which have disclosed a large number of new opportunities for medium and large-scale topographic mapping.

In this paper, we have developed a semi-automatic method to extract buildings in structured and unstructured urban settlements areas from high-spatial resolution panchromatic imagery. The proposed method uses radial casting algorithm to initialize snakes contours, and the fine measurements of building outlines is carried out using snakes model. The results are satisfactory with an extraction rate of 91 percent as demonstrated by examples over a variety of selected test areas. The potential, limitations and future work of our approach is discussed.

1. INTRODUCTION

Extraction of geospatial features from digital images for is one of the most complex and challenging tasks faced by computer vision and photogrammetry communities. Geospatial features and buildings in particular are required for varieties of applications such as urban planning, creation and updating of Geographic Information Systems (GIS) databases and creation of urban city models. In practice, the extraction of buildings from digital images is complex because buildings can have various complex forms and roofs of various compositional materials. For decades extraction of buildings from digital images have been carried out manually based on mono or stereo plotting using aerial photos. Manual based plotting is slow, expensive and requires well-trained operators; for rapid urbanizing and high-densely urban areas it cannot suffice Ruther et al., 2002).

Numerous efforts have been made in the past few years to automate building extraction from digital images (Gulch, 2000, Baltsavias et al, 2002, and Haverkamp, 2003). Fully automatic feature extraction systems until now are limited to specific applications and are not yet operational (Rottensteiner, 2001). In the absence of fully automatic systems, semi-automatic systems seem to be an alternative solution (Gruen and Wang, 1998, Rottensteriner, 2000). However, in recent years, we have experienced the emergence of high-resolution space borne images, which have shown potential for medium and large-scale topographic mapping (Toutin, 2002). In order to effectively utilize the potential of satellite image for building extraction, new methods and tools are urgently required.

In this study a simple but effective method is proposed, which extracts structured and unstructured buildings in urban settlement by measuring a single point on the approximate centre of the building. This method uses radial casting algorithm to initialize the snakes contour, and the modified snakes models for fine measurement of building outlines.

2. RELATED WORKS

Building extraction from digital images have been investigated for more than 20 years but still the existing methods are limited to specific applications. Brunn and Weidner (1997) distinguished two main tasks for building extraction from digital images: building detection and building reconstruction. These tasks are inter-related and cannot clearly be separated because the tasks involved in building detection can also be implemented in building reconstruction. Building extraction processes differ based on the model and prior information used. For example the use of geometrical representation with rectangular models (Weidner et al., 1995), use of multiple images (Ballard, 2000), and polyhedral shapes (Scholtze et al., 2002). Fischer et al., (1997) use lines, points and regions to describe building outlines.

In an effort to make building extraction processes efficient, various attempts to automate extraction processes have been reported. However, existing automated building extraction techniques are still operating at a very rudimentary level (Gruen, 2000). One first difficulty for automated techniques is caused by image variation in terms of type, scale, and required level of detail (Wang and Tseng, 2003). Secondly, automatic recognition of semantic information of an object using computers is very difficult; existing algorithms tend to fail whenever a new situation in image space is encountered or where objects are very close to each other (Gruen, 2000, Ruther et al., 2002,). A well-extracted building requires well interpretation of imagery to recognize its location and extent, and then automated processes are employed.

Sohn and Dowman (2001) proposed an automatic method of extracting buildings in densely urban areas from IKONOS images. In their study, they used large detached buildings without analysis of the accuracy and modelling of the structure details. Fraser et al (2002) compared buildings extracted from IKONOS imagery with those obtained using black and white aerial photographs to evaluate the potential of high-resolution images. Toutin and Cheng (2002) investigated the potential of Quickbird image for spatial data acquisition and showed that Quickbird sensors of 0.6m have narrowed the gap between satellite images and aerial photographs, which have resolution ranging from 0.2 to 0.3m. Ortner (2002) used optimization and destruction approaches simultaneously to extract buildings. He introduced a point process technique to extract well-structured

and symmetrical buildings. Haverkamp (2003) used linking edge chains to extract buildings from IKONOS images. Thomas et al (2003) assessed three different classification methods for extracting land cover information from high-resolution images. In their investigation, they concluded that high-resolution imagery is a valuable tool for mapping urban areas.

In general, most of the existing building extraction methods are based on generic models where buildings are assumed to follow a certain code. However, using generic models in areas where buildings does not follow any particular code such as those found in informal settlements areas, cannot provide realistic results (Ruther et al., 2002). Buildings in informal settlements areas are made of diverse materials, very close to each other and have no proper orientation which making the extraction process very difficult. There have been very few attempts to develop tools and methods to extract buildings in unstructured or informal settlements areas as compared to research efforts made thus far on buildings extraction. Recent reported efforts include: collection of social and spatial information (Barry and Rüther 1999), use of fused shadow data with 2D building blobs derived from normalized Digital Surface Model (DSM) and still video Kodak camera (DCS460c) to extract shacks in South Africa (Baltsavias and Mason 1997). In the work conducted by (Li and Ruther, 1997; 1999) an Informal Settlement Modeler was developed using DSM, shadow, and attributed linear feature data derived from low-cost small-format digital imagery.

A common feature of building extraction methods in informal settlements achieves their extraction process using a DSM or DEM. The main disadvantages of using DSM generated by image matching technique includes: insufficient ground sampling data and matching errors caused by poor image quality, occlusion and shadows which leads to poor definition of buildings outlines (Baltsavias et al., 1995 and Ruther et al., 2002). For the technology to be effective in an informal settlements environment, it must be flexible to cater both for structured and unstructured buildings (Ruther et al., 2002). Active contour models or commonly known as 'snakes models' at present seem to be an alternative and useful models to extract structured and unstructured objects from digital images.

3. SNAKES MODEL

3.1 Existing Snakes Models

Active contour models, or commonly known as "snakes," is defined by an energy function. The energy function, which is minimized, is a weighted combination of internal, image and external energy forces. The internal energy force describes the shape of the snake; the image force attracts the snakes to the boundaries of the object, while the external energy force comes from the image itself or a higher level of image processing. The solution of the snakes models are activated by its intrinsic trend of minimizing its energies. The function is defined in such a way that its energy reaches minimum when the snakes control points locks the object boundaries in the image space. Kaas *et al* (1987) represented a contour by a vector, v(s) = [x(s), y(s)], having the arc length *s* as a parameter, where *x* and *y* are the coordinates of a snakes contour point. The total energy of a snake model is represented as:

$$E_{Snakes} = \int_0^1 E_{Inter} V(s)) + E_{Ima}(V(s)) + E_{Cont}(V(s)) ds.$$

(1)

E_{Snake} represents the total energy of the snake,

E_{inter} is the internal energy function formed by the snakes configuration, and

E_{img} is the image energy, and

E_{Cont} is the external constraint force action on the contour. For each control point on the snakes contour, the total energy force can be represented as:

$$E_i = \alpha E_{cont_i} + \beta E_{curvi} + \lambda E_{ima_i} + \gamma E_{cont_i}$$

(2)

α, β, λ and γ at a snake control point are weighted coefficients used to determine the extent to which the contour is eligible to stretch or bend. The total snake energy is the sum of E_i over all the control points.

3.2 Limitation of existing Snakes Models

There are several limitations with the original snakes models, which have not yet completely solved. For example, It is difficult to determine the appropriate weighted coefficients of the energy functions which causes bunching up of snakes points in the image, and also there is no simple way of initializing snakes contours.

Several approaches have been proposed to remedy the above-mentioned problems. For example; the use of snakes and least squares method to extract buildings in 2D and 3D using aerial photography and satellite images (Trinder and Li, 1997). Cohen (1990) used pressure force to control the movement of snakes contour. Although this method works well in many cases, still the parameter that controls the inflating force is not easy to set especially for high level of noise in the image. Tabb et al., (2000) combined snakes and neural networks to detect and categorize objects in images. In their approach, a snakes contour is stored as a vector of (x, y) coordinates, and each (x, y) coordinate reflecting the position of different control point on the contour's spline. Then the coordinates are then used as input for in the neural network.

Kreschner (2001) use homologous twin snakes and integrated in a bundle adjustment. This method, however often fails when the system chooses wrong snakes contour. Ruther et al (2002) use snakes and dynamic programming optimization technique to model buildings in informal settlement areas. However, dynamic programming is computational expensive and it fails in more complex topologies. Guo and Yasuoka (2003) adopted a "balloon snakes model". In their approach, Multiple Height Bin (MHB) technique was employed to obtain the approximate snakes contour. MHB technique however, could not provide correct representation of the extracted objects. More recently, Ohlhof et al., (2004) use polygon composed of three vertices as initial control for the system. Then after the system initializes model and the vertices deformed until the result is reached.

3.3 Improved Energy Minimization Function

In our approach, we disregarded snakes external energy term, which creates boundary effects for unstructured buildings. Additionally, we fixed the weighted coefficients α, β, and λ

to a unit weight to allow uniform strength of the snakes energy terms. Our snakes algorithm being minimized is expressed as:

$$E_{Snakes} = E_{Cont} + E_{Curv} + E_{Im\,a} \qquad (3)$$

Where E_{Cont} and E_{Curv} are energy terms as expressed in equation (1). The first and second internal energy terms are briefly described in discrete form as follows:

    i)   Continuity term

Let $v_i = (x_i, y_i)$ be a snakes control point on an image space, from equation (3) is expressed as

$$E_{cont} = \bar{l} - \left| v_i - v_{i-1} \right| \qquad (4)$$

Where $\bar{l}$ is the mean distance between two snakes control points and it is expressed as

$$\bar{l} = \sum_{i=1}^{n} \frac{\left| v_{i+1} - v_i \right|}{n} \qquad (5)$$

Where n is the number of control points. This term constrained the snakes control points to have equally spaced avoiding points to be grouped in one point and at the same time minimizing the distance between these points.

    ii)   Curvature term

This term expresses the curvature of the snakes points and smoothness of the snakes contour and mathematically is defined as

$$E_{Curv} = \left| v_{i-1} - 2v_i + v_{i+1} \right|^2 \qquad (6)$$

    iii)   Image term

The image term describes the radiometric content of the image and it restricts the snakes points to move towards the points of highest gradient. The gradient of image at each control point is normalized to show small differences in values at the neighbourhood of that control point. In this case, the gradient magnitude is negative to enable control points with large gradient to have small values. An expression of the image term is defined as:

$$E_{im} = \frac{(Min - Mag)}{(Max - Min)} \qquad (7)$$

Where: E_{im} is the image energy term, Min is the minimum gradient magnitude in the neighbourhood Mag is the gradient magnitude at each control point, and Max is the maximum gradient magnitude in the neighbourhood. The image energy terms described above attract the snakes to the image points with minimum gradient magnitude.

3.4 Initialization of snakes contours

3.4.1 Radial casting algorithm

To effectively extract buildings using modified snakes models and solve initialization problem of snakes contour, we developed a radial casting algorithm for initialization of snakes control points. A single seed point called centre (C) is measured at approximate centre of each building object (Figure 1). The radial lines from this point grow radically and work as follows:
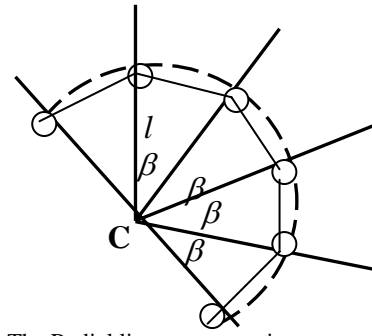

Figure 1. The Radial line representation

For each seed point (C):

    (i)   The contour's centre point C is measured, and from this point radial lines are projected outwards at definable angular intervals. The angular interval consists of four, eight, or sixteen radial lines ranging from $0^0 - 360^0$. The number of radial lines depends on the complexity of the building.

    (ii)   The distances of radial lines joining the central point C in the snake contour is computed; we term this radial line the *l's* lines.

    (iii)   The centre point C of the building polygon is always fixed and the radial distances to the snakes control points is variable depending on the size of the building object. Several different radial lines were tested to identify an optimal number of lines suitable for building extraction in informal settlement areas. Following this experiment, and based on the dynamics of buildings in informal settlements, 8 and 13 radial lines for simple and complex buildings respectively were adopted as an optimal number of lines for this application.

    (iv)   Each snakes control point in image space, advance to a new position where the gradient energy in a search window is maximum.

During radiation of the snakes control points from point C, it is possible that the snakes curve becomes smaller than desired. If this happens, the generated snakes control points can be deleted and a new centre point C can be established.

4. BULIDING EXTRACTION

4.1 Methodology

In this section the proposed methodology for extracting building outlines from high-resolution imagery is presented. There are three main features of our process, image pre-processing and building extraction.

4.2 Image pre-processing

To process high-resolution satellite images for subsequent building extraction, the operation aspects of the image acquisition have to be taken into consideration (Fraser et al., 2001). These aspects have effects on the homogeneity or non-homogeneity of image quality particularly in high-densely built-up areas. The image quality is mostly affected by variations in sensor view angle, sun angle, shadowing, and atmospheric conditions (Cheng and Toutin, 2002). These effects become worse in areas, where buildings roofs have various composition materials. For example, high-resolution images with 8 bits have a loss of information in shadow or in bright areas (Jacobsen, 2002). Rossi (2003) discussed difficulties commonly observed when dealing with urban shadowed areas. In his study, he recommended the use of 11-bits image in order to improve visual interpretation of objects.

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The variation in illumination conditions, shadowing and building density in urban areas makes it very difficult to distinguish individual buildings from its surrounding. In order to solve this problem, a non-linear anisotropic diffusion model (Weickert, 1999) was adopted and implemented to normalize the noise effects around the buildings. The diffusion process establishes a scale-space, which normalizes image noise concentration. The main objective of image normalization process is to bring the variation of pixels around the buildings at the same level. The diffused image is then used as an input in our snakes algorithm for subsequent extraction of the building outlines.

4.3 Building extraction

To effectively extract buildings using snakes models and radial casting algorithm, a human operator measures a single point at the approximate centre of the building in the image space and then the snakes points along the contour are automatically generated. As soon as the snakes points are generated, the user has an option to accept or reject the snakes contour. In the event of rejecting a snakes contour, a single snakes contour or all generated snakes contours can be deleted. Conversely, if the snakes contour is accepted, a minimization function is invoked, and for each snakes control point a 3 x 3 search window is performed to compute the minimum and maximum energy values in the neighbourhood. This process is iterative and at the end of this process, the point with a minimum energy value is selected as a new position in the image space. This is an iterative process and a final solution is reached when snakes contour locks the building outline.

5. RESULTS AND DISCUSSION

5.1 Data used and study area

The method developed in this study was applied to extract buildings from the areas of Dar Es Salaam city, Tanzania and Oromocto Township in New Brunswick. The images used were geo-rectified by the image vendor DigitalGlobe Inc. and have the following properties:

- Spectral resolution: four bands (R, G, B, NIR), 8 bits/pixel
- Spatial resolution: two metres/pixel (multispectral) and 0.6metre/pixel (panchromatic)
- Pre-processing: DigitalGlobe Inc. standard geometrically corrected (CEO) at position accuracy of 23m.

5.2 Building extraction results

The following section shows the results of extracted 2D buildings from informal settlement areas. The snakes model and radial casting algorithm have been implemented in a PC (Pentium (R) 4 CPU 1.80 GHZ processor) using standard C language. Figures 3 show portion of Quickbird image over Dar Es Salaam test areas, while Figures 4, and 6 demonstrate the results of extracted buildings in informal settlement and formal areas respectively. Figure 4 shows the result of 2D building extraction in vector layer. The result shows completeness of extracted buildings portraying adaptability of shapes and orientations of individual buildings.
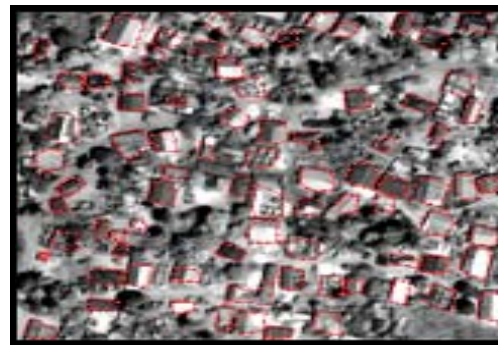

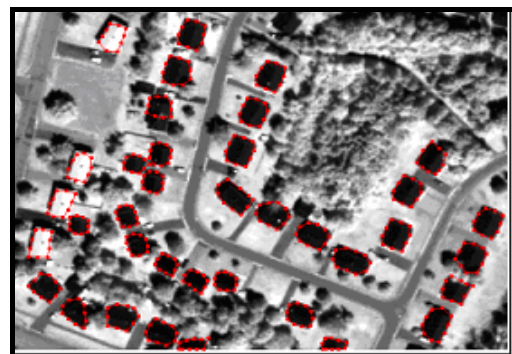
Figure 2. Extracted buildings for test area 1

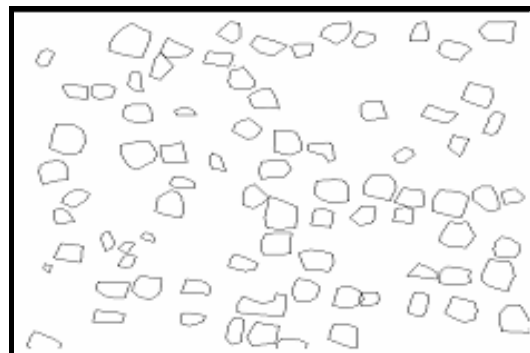Figure 3. Extracted buildings for test area 2

Figure 4. 2D building polygons (in vector layer) for test area 1

Although most of the buildings have different shapes and orientation, the snakes contours have moved sequentially to the boundaries of the buildings. Note that most of the buildings outlines were sufficiently extracted. However, we should mention that the preliminary results obtained in this study are satisfactory and promotes the use of snakes and radial casting algorithm can cope with structured and unstructured buildings.

6. ANALYSIS OF THE RESULTS

The analysis of the results includes qualitative and quantitative comparison of the 2D data acquired by the proposed system and ground truth data manually plotted using photogrammetric analytical plotter as well as comparison of time and effort required by the human operator.

6.1 Qualitative analysis

In the qualitative analysis the objective was to determine the practicability of the proposed approach whereby a building extracted percentage rate is calculated. For this metric, a

modified form of approach used by Avrahami et al., (2003) has been applied. In Avrahami's model a weighted parameter k = 0.5 for buildings partially mapped was used to compute the extraction percentage rate. Since the extraction process was carried out in the

same environment, each parameter in the model has equal contribution to the final computation of the building extracted rate. In our modified form, the building extraction rate is expressed as:

$$BER = \frac{BCE}{(BCE + BPE + BNE)} X 100 \qquad (8)$$

Where BER is the building extraction rate, BCE is the building correctly extracted, BPE is the number of buildings partially extracted and BNE is number of buildings not extracted. Table 1 presents the extraction rate in each test area. These results show that from three test areas, buildings were extracted at 93.6-percentage rate.

	Test Area 1	Test Area 2
BCE	74	36
BPE	4	1
BNE	2	1
Extraction Rate (%)	92.5	94.7

Table 1. Building extraction percentage rate from three test areas

6.2 Quantitative analysis

In quantitative analysis, building corner points from 2D vector layer were randomly selected and measured. The measured points were compared with their corresponding points from the ground truth data. A total of 20 points were measured on test area 1 as shown in Table 3 below.

Test areas	No. of points	RMSE (m)	Std dev. in x	Std dev in in y
Test area	20	1.22	0.80	0.98

Table 2. The RMSE and deviations of randomly measured building corner points

Based on 20 randomly measured points, the mean Root Mean Square Error (RMSE) was computed to determine the internal accuracy of the measurement. Then the standard deviations in x and y were also computed as summarized in Table 2. The results showed the standard deviation of 0.80m and 0.98 in x and y respectively. However, it is important to mention that the proposed method has not been able to clearly define building corners for some buildings in the same manner as appeared from ground truth data. The possible reason could be the closeness of buildings in informal settlements as well as the resolution of the image. To achieve higher accuracy in informal settlements using this method is difficult particularly when using a noisy imagery. The higher random noise effects in high–resolution imagery causes edges of the building along the corner of buildings to wobble from their correct positions.

However, as presented in Figures 4, 5 and 6, the final results are very close to the true building outlines, which strongly suggesting a need for post-processing stage to refine the edges if higher accuracy application is required.

6.3 Time comparison

The time for extracting a single building consists of the following parameters:
- Scene navigation
- Building extraction

The objective of this test was to provide an indication of the efficiency of extracting a single building between our system and manual system. Scene navigation time is recorded when the human operator is interacting with the image before building extraction process and building extraction time is the actual time used to extract a single building. The recorded time during experiment is illustrated in Table 3.

Time used for extraction a single building	Time used for each building (in seconds)	
	Semi-automatic	Analytical plotter (Qasco converted plotter)
Scene navigation	34	37
Building extraction	10	20
Total	44	57

Table 3. Time used to extract a single building in the test areas

Based on the same level of details between manual and semi-automated processes it was revealed that, the semi-automated process developed in this study reduced the time used to extract a single building by about 23%.

7. CONCLUSIONS AND FUTURE WORK

It was demonstrated that the modified snakes models and radial casting algorithm developed in this study improved the extraction rate by 23%, and delivered a significant contribution to the improvement of building extraction from high-resolution satellite imagery. This new method was applied to structured and unstructured buildings in urban settlements. In all test areas it led to a highly reliable result. Buildings with different shapes and orientation can be extracted with reliable accuracy.

Up to now, multiple point measurement from high-resolution satellite imagery is still a primary method for building extraction. The minimum time used to extract a single building is 57 seconds using conventional photogrammetric method (Ruzgiene, 2004). By using snakes models and radial casting algorithm, a single building can be reliably extracted in 44 seconds. This extraction time is significantly smaller than that of conventional photogrammetric technique. On the other hand, the method is faster, and does not require stereo viewing. Therefore, it is obvious that the accuracy of the new method developed in this study is sufficient for practical applications particularly for rapid growing urban areas.

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