SEMI-AUTOMATIC SYSTEM FOR BUILDING EXTRACTION
IN DENSE URBAN SETTLEMENT AREAS FROM HIGH-RESOLUTION SATELLITE IMAGERY

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ABSTRACT:
Recent availability of high-resolution satellite images provides a new data source for geospatial data acquisition. This high-resolution data source has made possible to extract man-made features such as roads and buildings, which are required for varieties of applications including urban planning, creation of GIS databases, and environmental monitoring. In this paper, we have developed a new method to extract buildings in urban informal settlement areas using high-spatial resolution panchromatic imagery. The proposed method uses radial casting algorithm to initialize snakes contours, and the fine measurements of building outlines is automatically carried out using snakes models. The building extraction results are satisfactory with an extraction rate of 94 percent as demonstrated by examples over a variety of selected test areas. The potential and limitations of applying this method to extract buildings is also discussed.

1. INTRODUCTION

Two commercial high-resolution satellites IKONOS and QuickBird were successfully launched in September 1999 and October 2001 respectively. Both satellites provides potential data source for urban mapping applications (Toutin, 2002). QuickBird has the highest resolution sensor of 0.61m in panchromatic mode and 2.44m in multispectral mode. However, due to the nature of high-resolution data, the extraction of man made features and buildings in particular pose many problems especially where buildings are very close to each other. Buildings in informal urban settlement areas are very close to each other, and have no proper orientation, which makes extraction process very difficult.
In order to effectively extract buildings in informal settlement areas, a new method for extracting buildings in informal settlements areas is proposed. This method is semi-automatic and uses radial casting algorithm for initialization of snakes control points and it is followed by automatic extraction of building outlines. The experiments were conducted in three test areas in Dar Es Salaam, Tanzania using QuickBird satellite imagery. The results from all test areas show the potential of high-resolution images for building extraction and the reliability this method can provide to extract buildings in informal settlement areas.

1.1 RELATED WORKS

Building extraction methods using aerial or satellite images have been investigated for more than 20 years but still the existing methods cannot be applied for production environment. Brunn and Weidner (1997) distinguished two main tasks for building extraction from aerial and space images: building detection and building reconstruction. These tasks are inter-related and cannot be separated because the tasks involved in building detection can also be implemented in building reconstruction.
Building extraction processes vary 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 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 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 use ancillary data and generic models for building extraction. However, using generic models in areas where buildings does not follow any particular code such as those found in informal urban settlements areas, cannot provide realistic results (Ruther et al., 2002). Buildings in urban informal settlements areas are made up of diverse materials, very close to each other and have no proper orientation. Therefore, extracting buildings in urban informal settlement areas is difficult and yet challenging. There have been very few attempts to develop tools and methods to extract buildings in such 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 existing building extraction methods in informal settlement areas, achieves their building extraction process using a DSM or DEM. The main disadvantages 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 both for structured and unstructured buildings. 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.

In this study we propose a new method for building extraction in informal settlement areas using high-resolution satellite images. The method consists of two main steps: image pre-processing, snakes contour generation and building extraction.

2. SNAKES MODEL

2.1 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:

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

Where

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

$E_{\text{int}er}$ 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:

$$E_i = \alpha E_{cont_j} + \beta E_{curvj} + \lambda E_{ima_j} + \gamma E_{cont_j} \qquad (2)$$

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.

2.2 Limitations 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, 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 and satellite images (Trinder and Li, 1997). Cohen (1990) used pressure force to control the movement of snakes contour. However, choosing the parameter, which 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 coordinates are 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. More recently, Guo and Yasuoka (2003) adopted a "balloon snakes model" to extracting building from IKONOS image. 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.

To effectively use snakes models to extract buildings in urban informal settlements using high-resolution satellite image, we present a modified form of snakes models based on William and Shah (1992) framework. The modified form solves the open problems described above, and introduces a radial casting algorithm for initialization of snakes contour for efficient building extraction.

2.3 Enhanced Energy Minimization Function

In our formulation, we disregarded snakes external energy term, which creates boundary effects for unstructured buildings. Additionally, we fixed the weighted coefficients α, β, and λ to unit weight to allow uniform strength of the snakes energy terms. Our modified snakes model is expressed as:

$$E_{Snakes} = E_{Cont} + E_{Curv} + E_{Ima} \qquad (3)$$

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, the first continuity term is expressed as

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

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

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

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.

i)   Curvature term

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

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

ii)   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.

2.4 Initialization of snakes contours

To effectively extract buildings using snakes models and solve initialization problem discussed above, we have developed a radial casting algorithm for initialization of snakes contours. This algorithm assumes that the snakes contour is closed, which is a reasonable assumption to make for building extraction. 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 generate points around the building object and it work as follows:
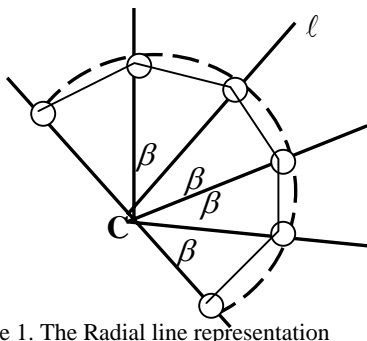

Figure 1. The Radial line representation

For each seed point C:

(i)   The contour's centre point C is calculated, and from that centre point a number of radial lines are projected outwards at definable intervals. These intervals may consists of four, eight, or sixteen radial lines whose angular ranges from 0^0 - 360^0 from the centre point C.

(ii)   The distances and directions of the lines joining the central point C with its adjacent point in the snake contour are computed; we term this radial line the *l's* lines.

(iii)   The centre point C of the building object 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 settlements. Following such experiment, and the dynamics of buildings in informal settlements, the 8 radial lines representation was adopted as an optimal number 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 minimum.

However, during radiation of lines from centre 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.

3. METHODOLOGY

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

3.1 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.

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.

3.2 2D Building extraction

To effectively extract 2D 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 initial snakes contour is automatically generated. As soon as the snakes contour is generated, the user has an option to accept or reject the snakes contour. In the even 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. The position 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.

4. RESULTS AND DISCUSSION

4.1 Data used and study area
The method developed in this study was applied to extract buildings from the area of Dar Es Salaam city, Tanzania (Figure 3). 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.
- Map projection: UTM Zone 39 WGS-84.

4.2 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. Figure 3 shows Quickbird image over Dar es salaam test areas, while Figures 4, 5 and 6 demonstrate the results of extracted buildings and some statistics, which allow the evaluation of its accuracy and robustness. The result shows completeness of extracted buildings portraying adaptability of shape and orientation of individual buildings. The snakes contours have moved sequentially to buildings boundaries of different shapes and orientation.

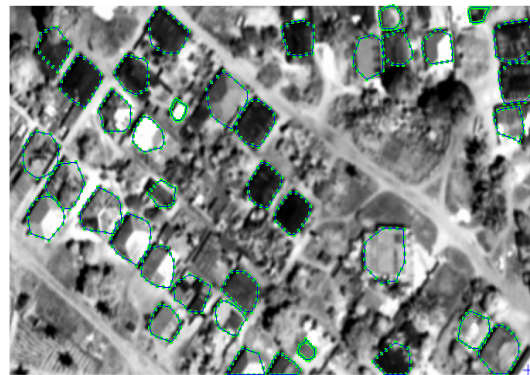Figure 3 –Portion of QuickBird image over Dar es salaam, Tanzania

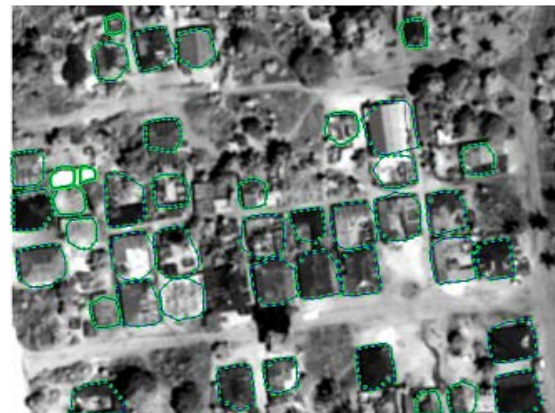Figure 4 - shows extracted building outlines

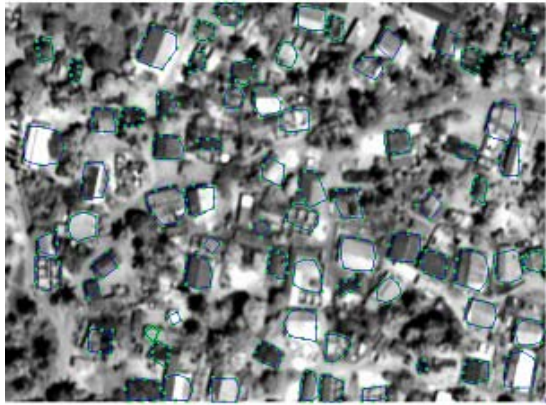Figure 5 - shows extracted building outlines

4

Figure 6 shows extracted building outlines

5. ANALYSIS OF THE RESULTS

To make the discussion on the extraction results more objective, the proposed semi-automatic building extraction method has been evaluated and compared with the reference data (ground truth) manually plotted using photogrammetric techniques. Qualitative and quantitative analysis have been applied separately to analyze the results.

5.1 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, we defined the following extraction types: Building Completely Extracted (BCE), Building Partially Extracted (BPE) and Building Not Extracted (BNE). For extracted buildings, completely extracted is referred when the snakes contour covers 100 percent of the building. Partially extracted is when the snakes contour covers the building less than 100 percent. The modified form for calculating building extraction rate is expressed as:

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

This evaluation was performed separately for each of the three test areas (Test area1, Test Area 2, and Test Area 3). Table 1 presents these statistics in each test area. These statistics show that the extraction rate for different test areas ranged between 92 and 94 percent. This extraction rate is higher compared to that of similar systems (Avrahami et al., 2004, Ruther, et al., 2002), reaching extraction rates between 62.3 and 76 percent.

	Test Area 1	Test Area 2	Test Area 3
BCE	60	70	73
BPE	5	4	4
Extraction Rate (%)	92.3	94.5	94.8

Table 1. Building extraction percentage rate from three test areas

5.2 Quantitative analysis

In quantitative analysis, building corner points from 2D vector layer extracted using this method, were randomly selected and measured. The measured points were compared with their corresponding points from the reference (ground truth) data. A total of 71 points were measured in three different test areas as shown in Table 3 below.

Test areas	Number of measured points	RMSE (m)	Std deviation in x	Std deviation in y
Test	20	1.22	0.80	0.98
Test area 2	29	1.16	0.84	0.79
Test area 3	22	1.11	0.41	1.03
Mean	71	1.16	0.68	0.94

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

Based on 71 randomly measured points, the mean Root Mean Square Error (RMSE) in each test area were computed to determine the accuracy of the proposed method. The statistics show that the root mean square error of 1.10m in planimetry was achieved. Additionally, the standard deviations of 0.68m and 0.94 in x and y respectively were achieved for three test areas.

6. CONCLUSIONS AND FUTURE WORK

In this research, a new method is proposed to extract buildings in informal settlement areas using high-resolution satellite images. The method combines snakes models and radial casting algorithm for effective building extraction. Experiments were conducted using Quickbird images with ground resolution of 0.6 metres. Experiment result show that the method is valid in extracting structured as well as unstructured buildings in informal settlement areas efficiently. It differs with the traditional photogrammetric multiple point measurements, and promotes a single point measurement procedure. However, it is important to mention that the proposed method has not been able to clearly define corners for some buildings in the same manner as appeared from ground truth data. The possible reason could be weak image energy forces exerted between individual buildings, which is mainly caused by high random noise effects in high–resolution imagery. High random noise effect causes edges of the building to wobble from their correct positions.

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