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Radial Casting Algorithm for Extraction of Man-Made Features from High Resolution Digital Satellite Imagery

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Abstract: The extraction of man-made features from high resolution digital satellite imagery is an important step to underpin management of geo-information in any country. Man-made features and buildings in particular are required for various applications such as urban planning, creation of geographic information systems databases and generation of urban models. Manual extraction processes are expensive, labor intensive, need well trained personnel and cannot cope with high demand of geo-information and changing environment. This paper, presents a Radial Casting Algorithm (RCA) used to extract buildings from high resolution digital satellite imagery. The algorithm measures only a single point on an approximate center of the building on an image and the fine measurement is automatically determined. The algorithm is a modification from original snakes model developed by Kass et al whereby the external constraints energy term is removed which negatively affects the convergence properties of the contour to provide the ability of the snake contour to cope with high variability of buildings on an image. The algorithm was tested on three areas of different environment. The quantitative measures were employed to evaluate the accuracy, efficiency and capability of the algorithm which shows that the time of extracting a single building was reduced by 32 percent, the extraction rate was 92 percent and the Area coverage of extracted polygons was 98 percent.

Keywords: Radial Casting Algorithm, High-resolution Image, Building Extraction

1. Introduction

The extraction of man-made features from high resolution digital satellite imagery is an important step to underpin management of geo-information in any country. Accurate and up to date man-made features and buildings in particular are considered as a basis of spatial data required for various applications such as urban planning, creation of geographic information systems databases and generation of urban models. Extraction of buildings from high resolution imagery is very expensive, labor intensive, need well trained personnel and cannot cope with high demand spatial data and changing environment. For decades, extraction of buildings from satellite image for urban planning has been carried out by conventional methods using analogue or analytical plotters which is expensive, requires well trained personnel, time consuming and cannot cope with high demand of spatial data. The high rate of development in urban areas and particularly in the developing world calls for an efficient and reliable technique to extract buildings for urban planning at higher accuracy.

According to the United Nations Centre for Human Settlement [1], about 40 percent of the world population would live in unplanned settlements. Also, it has been predicted that, in the next 30 years, two-thirds of the world's population will live in urban areas and 90 per cent of the population growth will take place in less developed regions such as East Asia, South Asia, and Sub-Saharan Africa. These are regions where capacity and resources are already constrained, and development challenges are ever more complex and concentrated. Urbanization in such areas is largely unplanned, fueling the continuous growth of informal settlements, physical manifestation of urban poverty and inequality [2], 2018). The report also pointed out that, urban

areas homes are 55% of the world's population [3], and it is projected to grow up to 60% by the year 2030, and 70% by the year 2050 [4]. Based on these facts, how can these incredible unplanned growth of cities be managed in a sustainable manner while conventional acquisition methods of spatial data for urban planning continued to be applied?

2. Existing Feature Extraction Methods

Extraction of buildings from aerial and digital satellite imagery have been investigated for more than three decades yet there is no single method which has been globally accepted as a solution to the extraction challenges. The possible reason could be due to variation of extraction methods due to the nature and complexity of data used. Most of the current developed techniques use Digital Surface Model (DSM) whereby [5, 6] developed Informal Settlement Modeler (ISM) using shadow and linear feature data derived from low cost small format digital imagery to extract buildings in complex buildings. The limitation of the ISM includes insufficient ground sampling data and matching errors caused by poor image quality, occlusion and shadows which leads to poor definition of building outlines. Some techniques used DSM direct from digital images or combining image and DSM [7, 8]. Huertas et al., used elevation data derived from Interferometric Synthetic Aperture Radar (IFSAR) with panchromatic image data to detect the presence of boundaries of individual building [9]. In their study, they used building shadows and sides to verify the existence of buildings. Yongguan X., et al used a PC-based incremental system to extract both road and building using IKONOS's stereo pair images to generate 3-D city model [10]. For each image set, they used the traditional Normalized Difference Vegetation Index (NDVI) to locate the vegetated areas to be used for masking, and apply the canny operator to the panchromatic images for edge detection. Also, they used the edge thinning and division algorithm to enhance the detected edges. However, the extracted the portion of buildings from the pan sharpened image, black holes are created which diminishes the accuracy of the system.

Li et al., used colour image acquired from airborne small format digital camera to map informal settlements [11]. In their study they developed a colour extractor using fuzzy similarity measure to hypothesize shark roof outlines. Although the method works well, but other non-building edges were also extracted from the image. In addition, lack of regularity of the buildings were noticed which indicated that many of the cues commonly used in the extraction process are less reliable [12]. Junfeng et al., used a remote sensing image service framework to providing static and dynamic web map service [13]. Mazhar, M et al., used real-time continuous feature extraction method to extract features in a large size satellite imagery [14]. In their study, the system uses Hadoop ecosystem to improve the efficiency of the system including collection, filtration, load balancing, processing, merging, and interpretation. The system was implemented on Apache Hadoop system using MapReduce programming technique with higher efficiency results in a massive volume of satellite ASAR/ ENVISAT mission datasets. However, the system was able to extract rivers, roads, and main highways. Usman, B and Zou, B used high resolution Satellite imagery data to extract cadastral boundaries using image processing algorithms [15]. The Satellite imagery was first rectified to enable the image to have the correct orientation and utilized this orientation to extract cadastral boundary features using computer vision and image processing algorithms. However, the algorithm did not captured well cadastral boundaries.

Miakshi, K and Ashutosh, B used Pleiades panchromatic and multispectral stereo satellite datasets of highly planned and dense urban areas to extract buildings [16]. The stereo datasets were first processed in a photogrammetric environment to obtain Digital Elevation Model (DEM) and orthoimages. DEM's were generated at 0.5m and 2.0m from stereo panchromatic and multispectral datasets, respectively. The orthoimages generated were segmented using object-based image analysis (OBIA) tools using conventional photogrammetric processes. Automatic extraction of buildings was developed but the algorithm tends to fail wherever a complex situation is encountered [17, 18]. Based on the current developed building extraction techniques, no single techniques has been globally accepted for extracting man-made features from a digital satellite imagery. For a technique or algorithm to extract man-made features from high resolution satellite imagery must be capable to cope with both structured and unstructured features. Therefore, more new models and algorithm are required to effectively extract man-made features from high resolution digital satellite imagery.

3. Proposed Methodology

3.1. Radial Casting Algorithm

In this study, Radial Casting Algorithm (RCA) is proposed which uses the concept of active contour model commonly known as "snakes" developed by [19]. The snakes model has been used extensively in computer vision and image analysis to detect and locate objects and describe their shape. The snakes' model can be categorized into two main categories namely regional based snakes model and boundary based snakes model. Regional based snakes' model usually moves a contour from the image space to well-defined regions. The regions of the image are examined pointwise in which the pixels belongs to which object in the image space is determined. The boundary based snakes model use continuous approximation of the image intensity to define the object boundary. A pixel is said to belong to a certain boundary only if the gradient of the image is minimum. Furthermore, snakes models can be divided into two types namely explicitly and implicitly models. Explicitly snake model include parametric representation while implicit model are based on scalar function. Xu et al., established the

relationship between explicit and implicit models and found that different applications require different snakes' models [20]. In addition, parametric snakes' models are derived from Newton's law of motion which allows the use of external forces in order to achieve a certain solution [21]. The snakes model consists of an elastic curve or surface which can dynamically conform with the object shapes in response to the internal and external forces. These forces are the result of a global function minimization process. The mathematical representation of parametric snakes' model is given as:

$$E_{snake} = \int_0^1 \{E_{int}[v(s)] + E_{image}[v(s)] + E_{con}[v(s)]\} ds \quad (1)$$

Where $v(s) = [x(s), y(s)]$, $s \in [0,1]$ is the parameterized active contour, E_{int} is the internal energy of the spline due to bending, E_{image} introduces the image forces, and E_{con} are the external constraint forces. The internal energy is a combination of elastic and bending term which is mathematically represented as:

$$E_{internal} = E_{elastic} + E_{bending} = \frac{1}{2}\int \alpha(s)\left|v_s\right| + \beta\left|v_s\right| ds \quad (2)$$

The external energy term is important in snake model as the final extraction result depends on how good is the image energy [22]. The gradient of an image is derived from the image that contains the object of interest. The image term is the combination of photometric energy terms which are calculated from the image function $I(x,y)$, pixel value, edge value and corner value. The image energy is represented as:

$$E_{image} = W_{line}E_{line} + W_{edge}E_{edge} + W_{corn}E_{corn} \quad (3)$$

Where:

$W_{line}, W_{edge}, W_{corn}$ and W_m are weighted coefficients of image terms;

$E_{line}, E_{edge}, E_{corn}$ are energy values for line, edge and corner respectively.

The snakes model have several advantages as compared to traditional image segmentation methods which includes the potential of energy term which enhances features on an image. The limitation of snakes model in some applications does not relate to the nature of the feature. In addition, in some cases the snakes contour is trapped by image noise which does not achieve a reliable result especially in complex environment [23]. Also, the snakes model fails to define polygon lines around an object and the difficult in selecting the weighted coefficients. Therefore, all these reasons limits the application of snakes model to extracting man-made features particularly in complex image environment. Different researchers used snakes model to extract features on an image. For example [24] used snakes and least squares method to extract buildings in 2D and 3D from aerial and satellite images. [25] utilized snakes model to extract building from IKONOS imagery. In their study, the building were selected and classified into simple complex buildings. In this approach, the snake contour and the weighted coefficients are manually placed to achieve better result. The algorithm is a modification of snakes model on

which it the external constraints energy term is removed which negatively affects the convergence properties and providing ability to cope with high variability of man-made features on an image.

3.2. Improvement of Original Snakes Model

Some techniques have been proposed to improve the snakes model [26] who introduced a growing snake as a solution to the initialization problem. They used a termination condition to drive the contour in image space. However, the termination condition causes the snakes contour to bunch around the object. Lai used the generalized Hough transformation to initialize the snakes contour. In the study, the Hough transformation only provides approximate locations of the object but cannot provide precise object boundary results [27]. Xu and Prince used gradient Vector Flow to force the derived from diffusion equation, the diffusion equation creates force which pulls the snakes contour away from the object which to a great extent reduced the sensitivity of the to the initial snake contour [28]. Rahman used a circular queue containing a list of (x, y) points manually to insert around the object [29]. Manual inserting position of snakes contour position (x, y) is computationally expensive because an operator has to add (x, y) points more frequently whenever minimization process of the snakes model fails. Ohlhof et al., applied three vertices to initialize the snakes contour iteratively [30]. However, from the user point of view, the approach has a higher number of iterations which tends to be expensive.

In order to effectively solve the limitations of the snakes model, the original snakes model was carefully analyzed whereby a robust and simple algorithm to extract man-made features from satellite imagery is developed. The Radial Casting Algorithm (RCA) developed in this study assumed that the snakes contour is always closed, which is a reasonable assumption for extracting building from an image. Given the nature of the buildings on an image, the original snakes model was modified on three key aspects namely; the effect of external constraints to unstructured buildings, the optimal selection of $\alpha, \beta, and \gamma$ and sensitivity to initialization. To effect these changes, the external energy term of the original snakes model was removed to allow the snakes model to cope with the high variability of the buildings on the image. Equation 3 below shows the modified of original snakes model.

$$E_{snakes} = E_{int} + E_{cons} + E_{curv} \quad (4)$$

Where:

E_{cons} and E_{curv} are energy terms.

Before initialization process, the number of snakes points and the radius of the snake polygon are specified by the operator into the RCA system, then a single point called C is measured at the approximate center of the object and from this point the contour radiates to generate the snakes contour around the object. Figure 1 shows the radial lines representation.
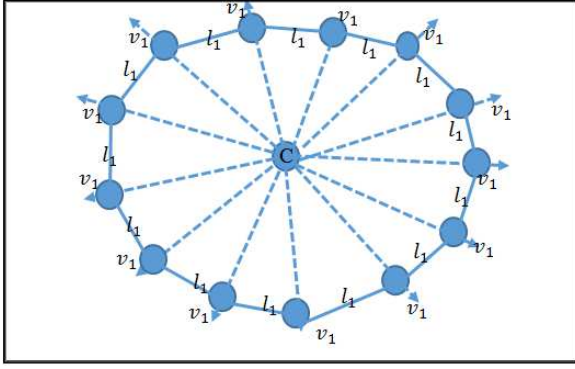
Figure 1. Radial lines representation.

From figure 1 above, the center point C is computed using x and y coordinates of the snake control points $v_1, v_2, v_3, \dots v_{n-1}$. The coordinates of the center C $(\bar{x}, \bar{y})$ for closed polygon region L are computes as:

$$\bar{x} = \frac{\iint x\,dx\,dy}{A} = \frac{\mu_x}{A} \qquad (5)$$

$$\bar{y} = \frac{\iint y\,dx\,dy}{A} = \frac{\mu_y}{A} \qquad (6)$$

$$R = \frac{1}{2}\mathrm{scsc}(\frac{\pi}{8}) = \frac{1}{2}\sqrt{4 + 2\sqrt{2xs}} \qquad (7)$$

$$A = \frac{1}{2}\sum_{i=0}^{n-1} a_i \qquad (8)$$

$$a = x_i y_{i+1} - x_{i+1} y_i \qquad (9)$$

Where:
A is the area of a polygon in image plane;

n is the number of polygon sides;
l is the distance between snakes control points.
Based on equations 3 and 4, for each measured point C:
The contour's centroid point C is calculated, and then radial lines s_i are projected outwards (Figure 1) at definable angular intervals. The angular intervals consists of either four, eight, or sixteen radial lines whose angular values range from 0°-360° from centroid point C.

The distances and directions of radial lines from the centroid point C are computed.

The centroid point C of the man-made polygon is always fixed and the radial distance is variable depending on the size of the man-made feature.

Each snakes control point along the contour moves to a new position where the gradient energy is minimum.

A stopping condition is imposed in the algorithm to control the radiance of the of the snakes contour.

4. Experimental Results and Discussion

The RCA Algorithm developed was tested in three areas using a high resolution satellite imagery in Dar es Salaam Tanzania (Figures 2, 3 and 4). The first step in implementing RCA is initialization of the snakes contour. An operator first specifies the number of snakes point and radius of the polygon. Once this process is complete, a single point is measured at the approximate center of the building and automatically the algorithm generates the snakes contour. After the snake contour has been generated, the minimization function is invoked for fine measurements of the building outline as indicated in Figure 2 below.
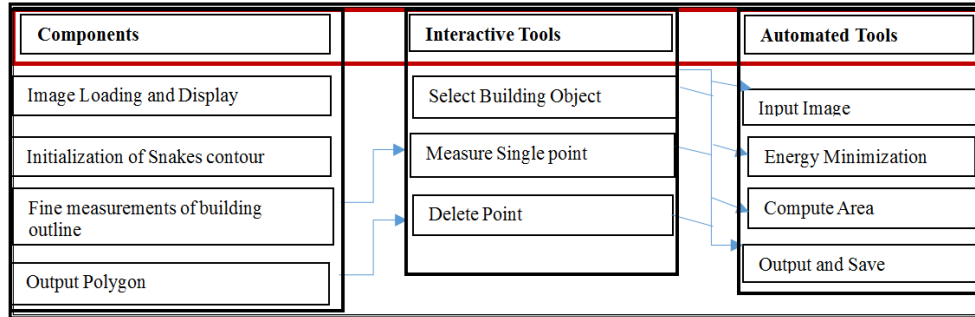

Figure 2. RCA algorithm Architecture.
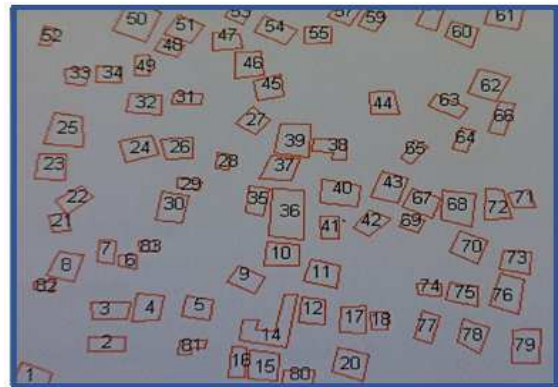

Figure 3. Extracted buildings Test Area 1,

Figure 4. Output polygons Test Area 1,

Figures 3, 5 and 6 shows the extracted buildings outlines from satellite imagery results using the RCA while Figures 4, 7 and 8 shows the output vector file for test area 1, 2 and 3 respectively.

Figure 5. Extracted Buildings Test Area 2,
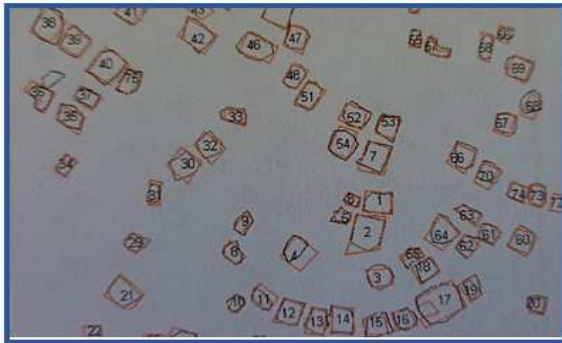

Figure 6. Extracted Buildings Test Area 3.

Figure 7. Output polygons Test Area 2.

Figure 8. Output polygons Test Area 3.

4.1. Analysis of the Results

The quantitative assessment of the extracted buildings polygons were compared with the reference buildings manually extracted from the same image using ArcGIS software. Two assumptions were used to determine the completeness of the extracted building. If the area of extracted building area covers 80 percent of the building, it indicated that it is completely extracted, and if it is less than 80 percent is partially extracted. The 80 percent area coverage is a reasonable assumption due to the fact that the RCA algorithm used mathematical representation while a human operator manually detects and extracts the feature with higher accuracy. In the proposed algorithm, the geometric accuracy of the extracted building polygons was determined whereby the coordinates of corners of the buildings were measured and compared with their corresponding points from reference data manually measured using ArcGIS software. A total of 75 corner points of buildings were randomly measured from the extracted buildings. The geometric accuracy were calculated from the output image and the standard deviation (SD) which measures the statistical dispersion of measured points were determined using equation 4.0 below. Table 1 shows the SD of measured points, Table 2 shows the extraction rate and Table 3 shows the area coverage of polygons.

$$\sigma = \sqrt{\frac{1}{N}\sum_1^N (x_i - \bar{x})} \qquad (10)$$

Where: σ *is the standard deviation*;
x_i are the measured corner points;
$\bar{x}$ is the mean value of the measured points.

Table 1. Standard deviations of the measured corner points.

Test Area	Number of measured points	SD in x (m)	SD in y(m)
1	24	0.93	0.83
2	22	0.35	0.42
3	29	0.29	0.55
Mean SD		0.52	0.60

Table 2. Extraction Rate for Test 1, Test 2, and Test 3.

Description	Test 1	Test 2	Test 3
Buildings completely Extracted	64	28	76
Buildings Partially Extracted	5	4	3
Buildings not Extracted	0	0	0
Total Number of Buildings	69	32	79
Extraction Rate by RCA (%)	92.7	87.5	96.2

Table 3. Area coverage of polygons for Test Areas 1, 2 and 3.

Description	Number of polygons	Area coverage (%)
Test Area 1	64	97%
Test Area 2	5	101%
Test Area 3	76	96%
Mean		98

4.2. Efficiency of RCA

The efficient of RCA was determined by measuring the time spent by human operator to extract a single building from an image. The RCA was integrated with an automatic

system to record every activity during the extraction process. The time used to extract a single building on an image consists of three parameters namely; time for scene navigation, time for building extraction, standby time and system time. Table 4 below shows the extraction time recorded for manual extraction and RCA system.

Table 4. *Time Used to extract a single building.*

Description	Time used for extracting single Building	
	RCA system	Manual operation
Scene Navigation	34	37
Extraction of simple building	10	20
Extraction of a complex building	12	35
Building Enhancement	4	6
Total time used	60	88

Based on the above comparison, it shows that the proposed RCA algorithm reduced the time to extract a single building by 32%. Also, it indicated that, it reduces human operator fatigue during the extraction process. However, apart from reducing extraction time, there are several factors which affected the performance of RCA including; low image contract, image noise, shadow, occlusion, building type on image.

5. Conclusion and Recommendation

Based on the course of this findings it can be concluded that:

The RCA is developed to overcome the problems of initialization of snakes contour in the original model. In the RCA, the initialization of the snakes contour is effected by measuring only a single point of a building.

The RCA algorithm is simple process and can be used by a non-mapping specialist and the time used to extract a single building whether is a simple or complex saves time by 32%. In addition, the interactive tools developed in the RCA turned out to be of great advantage.

The extraction of buildings from panchromatic image revealed that about 15% of the buildings were not extracted as some buildings could not be detected by the algorithm. Therefore, for RCA to work effectively a clear image is required.

The extraction rate determined from three test areas shows that, the extraction rate using RCA is 92%.

The Graphical User Interface (GUI) developed in RCA display 2D images on the computer which allows a human operator to view the image and it provides other functionalities such as tools for area calculations of extracted polygons and deleting snake contour if the initialization process is poor.

Although the proposed RCA worked well to extract building in three test areas, there are some possibilities to improve the algorithm. The improvement could be to initialize the center points for all buildings on an image and then the algorithm could extract all buildings together in order to save extraction time.

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