DETECTING BUILDING CHANGES FROM AERIAL IMAGES USING HEIGHT INFORMATION

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ABSTRACT:

A new approach of detecting urban building changes using edge detection and VLL (vertical line locus) matching method is presented. The approach mainly contents three steps. First step, edges are extracted using EDISON edge detector and then edge splitting and linear regression is done to get linear edges which may belong to buildings. Second step, buildings are verified and located by stereo matching and edge grouping technique. Third step, buildings are validated if changed according height change using VLL matching strategy. Two multi-temporal aerial stereopairs are used for test, and results proved our approach is encouraging.

1. INTRODUCTION

Change detection from aerial images has wide applications, such as map update, city planning, military reconnaissance, environment supervision, etc. And also it is widely researched to find urban building changes using multi-temporal aerial stereo pairs.

Many change detection methods for aerial and satellite images have been proposed, and can be concluded to three main methodologies. Firstly, methods are mainly based on grey information. Sakamoto et al. (2004) found changes using image matching and registration method based on non-linear self-adaptation mapping. Borchani et al. (2004) detected changes after classification by texture features. Ryu (2004) found urban changes using morphological filters. Carlotto (2005) detected men-made objects and changes by a cluster-based approach. Secondly, methods are based on geometry features, which mainly are edge feature. Rowe and Grewe (2001) detected linear object's changes in aerial images using edge detection and edge matching method. Dieking et al. (2000) researched linear object's change detection in SAR images. Thirdly, change detection methods are based on 3D information. Huertas and Nevitia (2000) firstly matched buildings in new images with known 3D model of buildings, and then analyzed building changes. Jung (2003)] generated DEM with aerial stereopairs first and classified images as buildings and non-buildings. Vosselman et al. (2004) got urban height information from laser scanning data and judged building's change by height.

Methods based on grey value are greatly influenced by different illumination, atmosphere, plant growing, and digitalization. The different position and orientation of images also make geometry distortion. And methods based on edges can find building's edges easily, but still have their shortage. Firstly, it cannot be assured that the counterpart edges of buildings are extracted the same time. Secondly, one edge may be matched with several edges in the other images for edge is often broken. Methods based on DEM are robust to urban building change detection. However it is very difficult to produce precise DEM for dense building areas by stereo-matching technique (Shi and Shibasaki, 1995; Murakami et al., 1999).

We propose a new building change detection approach which combines methods mentioned above and overcome their shortcomings. Firstly edges are extracted to assist locating buildings. But we do not match edges. On the contrary, points in stereopairs taken by the same time are matched to help verifying if edges are belongs to buildings. Then VLL matching technique is used to obtain the new height of matching points on building tops in old images. So height information is used to locate buildings and validate buildings whether changed but producing DEM is not needed. At last, if the height changes to a degree, we judge the building has changed, which is a more robust feature than grey and edge considering detecting building changes.

2. METHODOLOGY

2.1 Linear Edge Extraction

In this step linear edges potentially belong to buildings are extracted.

We compare several edge detection algorithms and find they are all adequate for our building edge detection process. And EDISON (Meer and Georgescu, 2001) algorithm is selected to detect edges on image. EDISON is improved on traditional Canny edge detector by embedded confidence measure, and can restrain image noise more effectively and have fine response to weak edges. Fig. 1 (b) is an EDISON edge detection image from an urban region of aerial image.

Almost every building has Edges be extracted in Fig. 1 (b) but some edges belong to trees, roads etc. are extracted too, which should be eliminated. Since building edges basically are linear, extracted edges then split using LPD (Longest Plumbline Distance) method recursively and are regressed to linear segments, non-linear edges are eliminated.

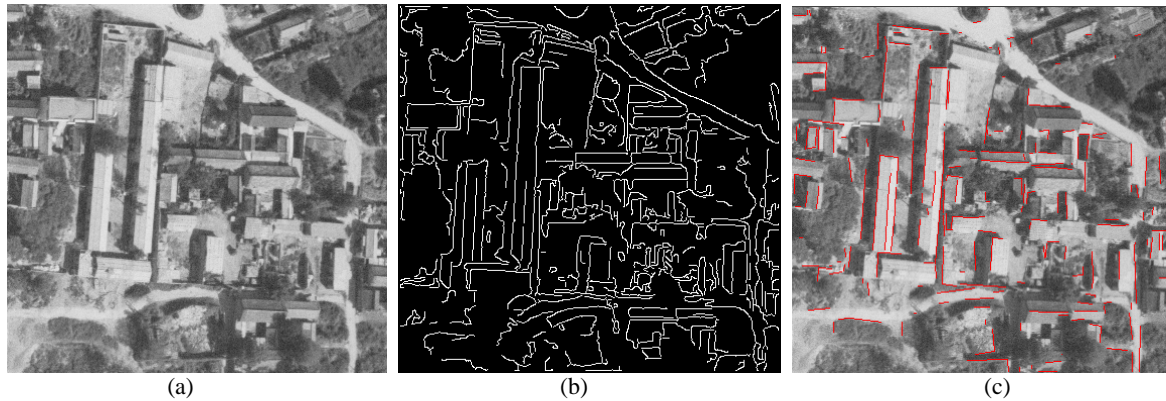(a)   (b)   (c)

Figure 1. Image (a) is an original image, and (b) shows EDISON edge map, and (c) are image with linear edges

Figure. 2 is the LPD splitting method. For every edge pixel between end "A" and "B", the plumbline distance is calculated, and the maximum distance "MaxD" and correspondence node "C" are recorded. Then new nodes are calculated between "A" and "C" and between "C" and "D" recursively until "MaxD" is less than the given threshold.
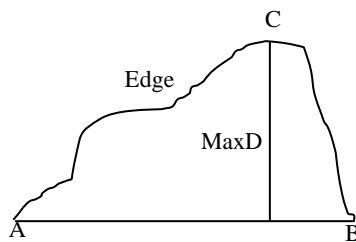

Figure 2. LPD splitting method

The split edges are then regressed to linear ones by least square adjustment. In eq. (1), "*b*" and "*a*" denote slope and intercept of regression line, and x_i, y_i are coordinate of edge pixels, and $\bar{x}, \bar{y}$ are mean value of *x* and *y* coordinates and *n* denotes number of edge pixels.

$$b = \sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y}) / \sum_{i=1}^{n}(x_i - \bar{x})^2 \qquad (1)$$
$$a = \bar{y} - b\bar{x}$$

After splitting and regression, most edges split to line segment, but some non-building edges with tiny toothed or wavy shape cannot split furthermore and will be remained. So in linear regression process constraint equation is added to avoid this instance. Eq. (2) calculates the residual deviation *Q*, and if *Q* is more than a given threshold, the edge is removed.

$$Q = \sum_{i=1}^{n}(y_i - a - bx_i)^2 / n \qquad (2)$$

We take out the short edges and those edges which direction does not match the main direction of buildings for convenience, and the remains will be regarded as building edges. Fig. 1 (c) is the remained linear edges after splitting and regression.

2.2 Building Edge Verifying

In this section we verify remained linear edges belong to buildings or to playground, fence, etc. by stereo matching technique.

If the edge belongs to buildings, the both sides of it are roof and ground, which have different height and bring to parallax non-continuity in image space. We select some matching points on both sides of edges, and the selecting rule is, first create two parallel lines of same distance from the edge, and then select points on the two parallel lines per fixed interval, and two ends are included. Then the counterparts are matched in stereopairs using traditional pyramid matching and least square matching technology. We suppose the orientation of aerial images is known and after forward intersection the object coordinate of the matching points will be gotten. If the height of those object points on both sides has obvious diversity, we consider the edge belongs to buildings preliminarily, otherwise belongs to roads, etc. Fig. 3 (a) is the selected matching points on both sides of all linear edges should be verified.

Points on and below trees or other objects which have adequate height above the ground may have obvious height difference too, so parallax continuity constrains are introduced in matching process. Building's top side has the same grey value and same height, but the ground side does not behave like that. It is called half flanking region of edge segment (Mcintosh and Mutch, 1988; Henricsson, 1998). We calculate grey means and deviations of matching points on one side, if they are very similar, consider it is the half flanking region and add parallax continuity constrains. Fig. 4 denotes the half flanking region on building top.

Figure 4. Half flanking region

If the check-up region is on flat ground, the process will be simpler. When the height of matching points is bigger than a set value, and points satisfy parallax continuity constrains, it can be concluded that points are on building top. So calculating height difference on both sides of edge is not necessary.
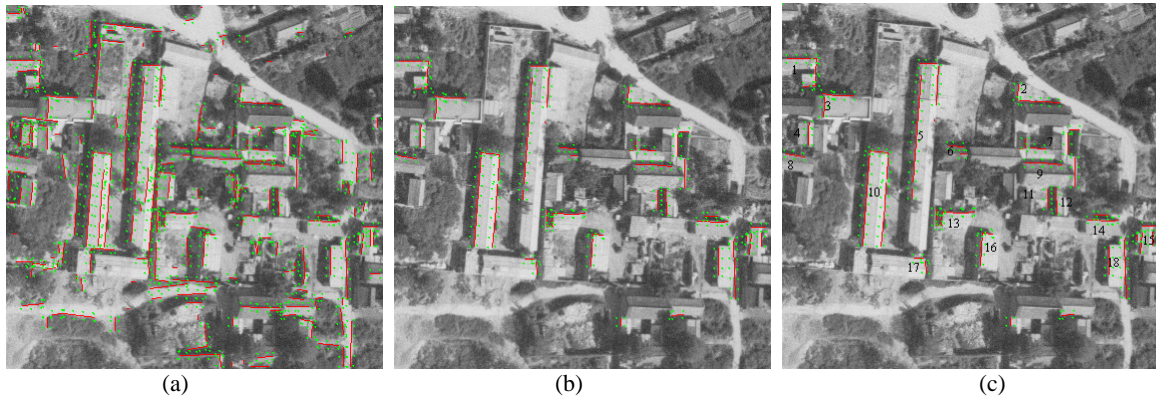

(a)   (b)   (c)

Figure 3. Matching points beside edges (a), and verified building edges (b), and separate and located buildings (c).

In flat region the mismatching problem as points occur in shadows will not be considered. But when the region is not so flat and the buildings are relatively low, height difference should be calculated. The matching points which in shadows usually do not have their counterparts, and make matching failed. We judge it is a shadow region on ground if the points on one side of edge all have relatively small correlation coefficient, and with low grey value, usually below 80. And then judge the edge whether belongs to building according to matching results of another side of the edge.

Deal with all edges one by one. And Fig. 3 (b) is the building edges have been verified.

2.3 Building Edge Grouping

After non-building edges are eliminated, the remains should be grouped to separate buildings so that the building number is gained and buildings are located. Edge grouping is a key problem of building extraction, and main hypothesis is that 3D line segments are coplanar. In most cases, edges on one building can not be all extracted, and sometimes only one or two edges are extracted. If buildings are close, and have the same height, the separate edges usually cannot be grouped correctly. In this paper a grouping strategy is proposed to mainly deal with rectangular-shape buildings using 3D relationship between edges and matching points.

Firstly the projection distance between line segments is calculated. In Fig. 5 the lesser perpendicular of M and N represents the projection distance of segment *ab* and *cd*. Search the segments one by one, and if the projection distance is below the set threshold, the segments may belong to the same building and go the next judge.
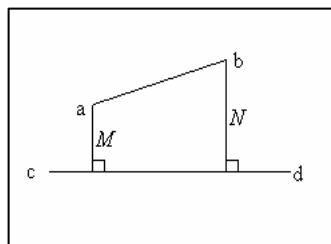
Figure 5. Projection distance

Secondly, height of segments which is presented by the average height of matching points on building top is compared. If it is almost the same, they may be edges of the same building and go the third step.

Thirdly, concept of "inner point" is imported to describe the geometry constraints that can obviously reduce the false grouping when edges are very close and have the same height. If two parallel edges belong to the same building, the matching points on building are must in the middle of them; if two perpendicular ones belong to the same building, the matching points are must inside the internal angle of them. We call those matching points inner points if they satisfy the above relationships and the corresponding edges are grouped to the same building. Fig. 6 represents two near buildings of the same height on which 6 edges are extracted. Some matching points are inside the internal angles of segments 1, 2 and 3, and the others are inside segments 4, 5 and 6. So segments 1, 2 and 3 are grouped to one building, and 4, 5 and 6 to another, and segments 2 and 4 which are close and the same height will not be grouped.
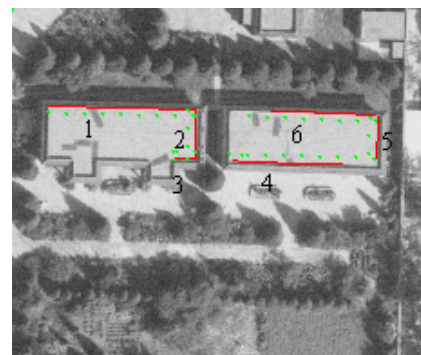

Figure 6. Edge grouping

After deal with all edges one by one, and alone and short ones are eliminated, edges are grouped to separate buildings. Fig. 3

(c) shows the edge grouping result. And 10 buildings are acquired and located.

2.4 Building Change Detection Algorithm

The matching points on building tops are kept, whose object coordinates present the height of buildings. And if they are changed, we can conclude that the building is changed. It is appropriate to use vertical line locus (VLL) matching algorithm based on object space to check whether height of matching points is changed. The VLL matching algorithm process goes as below:

1. Calculate image coordinates of matching points in new aerial stereo pairs according to collinearity condition equation. In Eq. (3) $a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2, c_3$ represent elements of orientation matrix of new images, and x, y, f are the image coordinates and focus. And X_A, Y_A, Z_A are object coordinates and X_S, Y_S, Z_S are linear elements of exterior orientation.

$$x = -f \frac{a_1(X_A - X_S) + b_1(Y_A - Y_S) + c_1(Z_A - Z_S)}{a_3(X_A - X_S) + b_3(Y_A - Y_S) + c_3(Z_A - Z_S)}$$
$$y = -f \frac{a_2(X_A - X_S) + b_2(Y_A - Y_S) + c_2(Z_A - Z_S)}{a_3(X_A - X_S) + b_3(Y_A - Y_S) + c_3(Z_A - Z_S)}$$

$$(3)$$

2. Look image coordinates of points on building top in new aerial stereo pairs as start matching points. If points can match well, it means the ground object does not change. And if match failed, means the object height Z_A is changed. Change Z_A step by step in an extension of Z_{min} and Z_{max}, until image points can match well and accordingly a new Z_A is gotten. The vertical line in object space is still a line which is through nadir point in image space. Eq. (4) expresses the line segment equation, and in which $x_{max}, y_{max}, x_{min}, y_{min}$ is the end points of the segment obtained by taking Z_{min} and Z_{max} in eq. (3), and *k, b* are the slope and intercept. So it can also search the most matching points in the segment pixel by pixel in images space besides changes value of Z_A in object space.

$$k = (y_{max} - y_{min})/(x_{max} - x_{min})$$
$$b = y_{max} - k x_{max}$$

$$(4)$$

3. Find all the new Z coordinates on one building, and calculate the mean and compare with original one. If the difference is below the set threshold, usually 0.5-2m, according to the image scale, consider the building does not change. And if height reduces to some degree, we consider the building has disappeared or diminished; if it is increased, we consider the building is heightened.

In the same way, we extract buildings on the later aerial pairs, and validate if they are new buildings.

3. EXPERIMENT AND ANALSYS

3.1 Threshold Setting

In process of linear edge extraction, the minimum edge length is set 5 pixels, and edges whose length below the value are not considered. Plumbline distance threshold set 3 pixels. The edge angle range set $\pm 10^\circ$ if parallel with main edge direction, and set $90^\circ \pm 10^\circ$ if vertical. Those thresholds are performed stable in the process.

In process of building edge verifying and grouping, the distance between matching points and edge is set 5 pixels, and one point is selected per 10 pixels and two ends included. The minimum relation coefficient in least square matching is set 0.8. If the coefficients are below it, check the matching points are if in shadows which grey value set below 80. The height difference threshold of two sides of edge is set 2m. In edge grouping the projection distance threshold is set 15 pixels and height difference set 0.5m. Those values are highly correlative with image scale and building's type.

In process of change detection, the height searching range is set ± 30 m. Change detection threshold is set 2m, and more than 2m is considered as changed buildings.

3.2 Experiment

Test 1 is shown in Fig. 7. The image size is 378*365 pixels. Fig. 7 (d) marks the change area. In ellipse A the building has changed. In ellipse B the building has disappeared. And in ellipse C the building change is failed to detect due to the direction of building does not compare the main one.

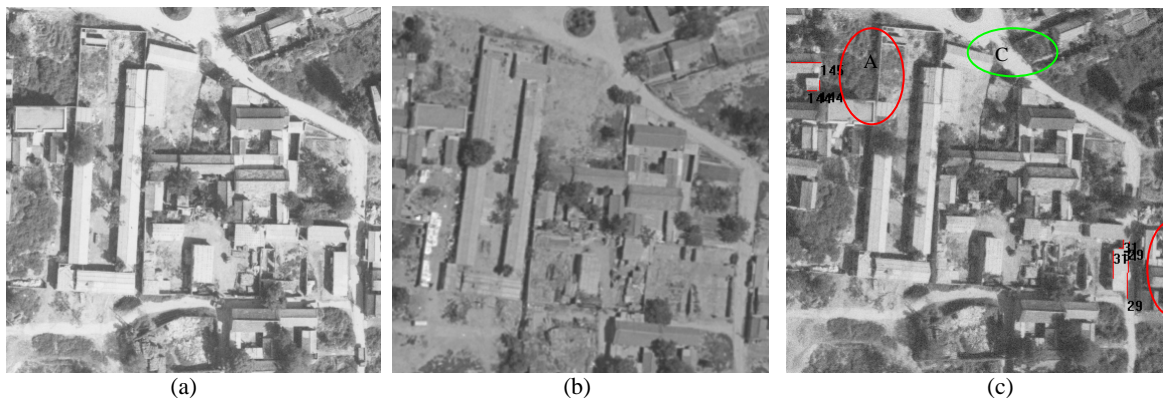(a)   (b)   (c)

Figure 7. Test 1. old image (a) and new image (b), and change detection map (c)

Test 2 is shown in Fig. 8. In this region the building layout is relatively regular and some buildings are on construction. Fig. 8 (d) shows the linear segments after edge extraction, edge splitting and linear regression. Fig. 8 (e) is the result of edge verifying and grouping. And Fig. 8 (f) is change detection results. The changes in ellipses A and B can clearly be detected. difference is near the set threshold, we judge the buildings have

The five buildings in ellipses C and D usually can not be detected by methods based on grey and edge features. In our method the new height of matching points is gotten which behaves fluctuant and not satisfies half flanking region condition. Although the mean of height
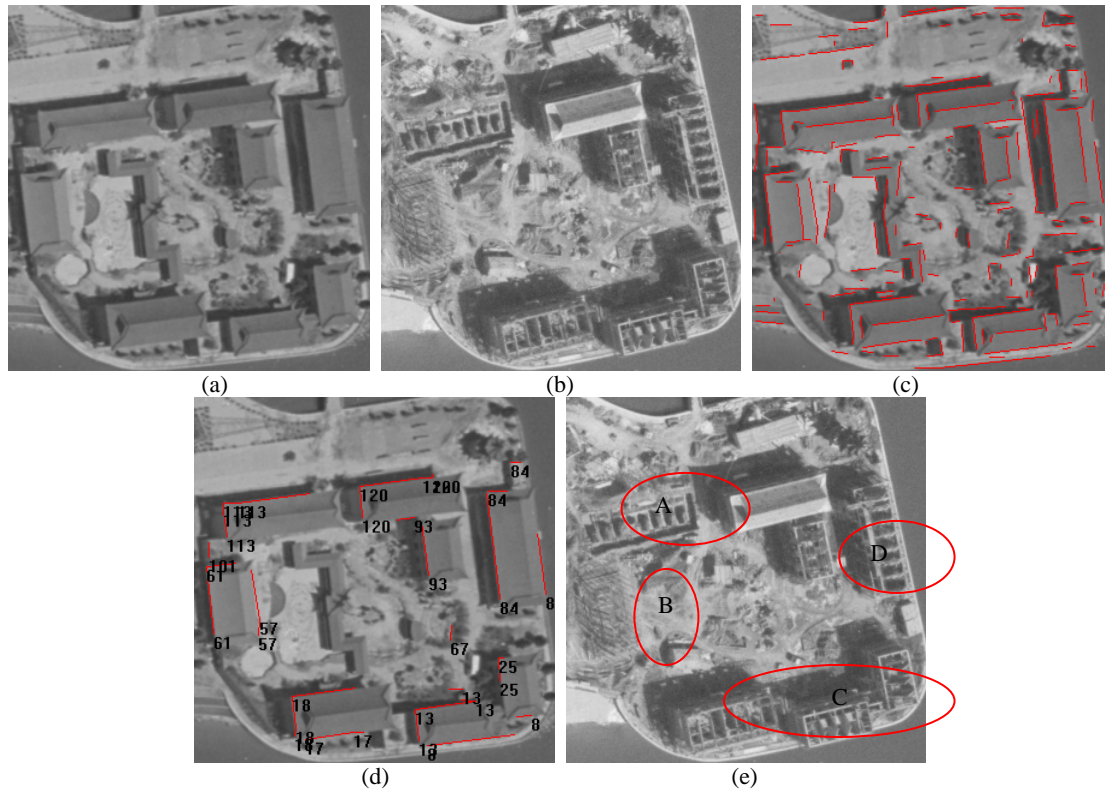
been changed.

(a)   (b)   (c)

(d)   (e)

Figure 8. Old image (a), new image (b), linear edge extraction image (c), edge verifying image (d) and change detection image (e)

3.3 Analysis

The detection rate of test 1 is 66.7%, and of test 2 is 88%. The cause of miss detection in test 1 is that the building direction does not compare the main one. And if main direction is not considered or the angle restrict is loosen, the missing rate will decrease. The miss detection in test 2 is caused by the building itself which is very low and image scale which is 1:15000, and if image of larger scale is employed, more precise coordinates will be gotten and detection rate will be increased.

4. CONCLUSION

Our method has some advantages. Firstly, we use height information to testify the buildings whether changed. Height information is more robust than grey value, which changes greatly due to different seasons, light condition, and sensor pose, and robust than edge information, for the counterpart edges are not assumedly extracted on different images. Also, we can find the changes if building is heightened or diminished, which is impossible for those methods based on grey features or linear features.

Secondly, our method does not need to generate DEM. DEM generating methods based on stereo-matching are time

consuming for the vast matching points. Our method only matches those points on the both sides of "maybe" building edges, and then matches points on buildings by VLL method. It needs much less workload compared to dense matching method.

Thirdly, directly matching points in images taken by different time is very difficult, and will bring on a number of wrong matching-points. On the contrary, we only match points in the stereo pairs taken by the same time. The stereo-matching technique is very mature and we can get quite approving matching-points.

At last, we solve the edge grouping problem of rectangular-shape buildings combining with the matching point's information, and in geometry it is rigorous.

Our method presumes that the orientations of aerial images are known. For the main purpose of cartography, and for development of Positioning and Orientation System (POS), aerial images are almost provided with orientation elements.

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