Change Detection Based on DSM and Image Features in Urban Areas

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1 Introduction

Fast change detection of urban areas is very important to the city management as well as updating the urban geography information. Urban landscape is subject to dynamic changes due to new construction and reconstruction of urban features. Manually updating the data is a formidable task. An automatic or semi-automatic method for data updating will increase the speed greatly. Automatic detection and modeling of cultural features from aerial images has become important in practice. Change detection is an important content in image understanding. It provides change detectors automatically correlating and comparing between two sets of imagery taken of the same area at different times and displaying the changes and their locations to the interpreter. Because of repetitive coverage at short intervals and consistent image quality, remotely sensed data from earth-orbiting are often used for change detection. However, the resolution of spatial remote sensing images is not high enough for change detection of man-made objects in urban area, while the aerial images can be used in urban change detection. From the end of 1960’s to the beginning of 1970’s, change detection techniques have been widely applied in change analysis of land use, monitoring of shifting cultivation, study of seasonal changes in pasture production, crop stress detection and other environmental change detection(1-3). It can also be applied to update the data of GIS.

2 Review the Previous Methods

Usually, the change detection involves registering two
or more spatially remote sensing images acquired on the same ground area at two different times. According to the functionality of the techniques, we can classify the current change detection techniques into two broad categories:

1) Change mask development (CMD). Only changes and non-changes are detected and no categorical change information can be directly provided.

2) Categorical change extraction (CCE). Complete categorical changes are extracted.

In CMD, changed and non-changed areas are separated by a preset threshold according to the result from comparing the spectral reflectance values of multi-temporal raw satellite images. The amount of changes is a function of the preset threshold. The nature of changes is unknown directly from these techniques and needs to be identified by other pattern recognition techniques. However, most change detection methods fall into CMD. For example, image differencing, image rationing, image regression etc. lead to the development of a change mask. The techniques in CMD usually cannot identify what types of land cover changes have taken place in the area of interest. For example, the land cover changes from agricultural fields to urban lands are recognized as changes only rather than changes from agricultural lands to urban lands. In CCE, however, the explicit categorical changes are detected directly on the basis of the spectral reflectance of the data. There are mainly three techniques of CCE: change vector analysis, post classification comparison, and direct multi-date classification. In one word, many interactive change techniques are in practice today. However, there are many problems associated with these manual or semi-automatic processes, such as time-consuming, inconsistency, etc. Therefore, a reliable and automated change detection system that can provide complete categorical land cover transitions is crucial in the environmental remote sensing and its regional or global implementation.

In this paper, the change detection of man-made objects in aerial images is introduced. We can apply the information of the height of houses to reinforce the change detection of houses, the reliability and efficiency of detection methods will be improved greatly. On this viewpoint, a new approach taking advantages of both height information from image pair and texture information from image is proposed to detect the change of houses in urban areas. In the stereo image analysis, new and old digital surface models (DSMs) are created automatically by image matching. By comparing the new DSM with the old one, the changed regions are extracted. It is known that this potential changing region may be the change of the height of trees and may be those of the building. In order to analyze the region, the method based on line feature matching was analyzed, but this method was greatly influenced by the straight line detected. So, the method based on gradient direction histogram was provided. Experimental results have confirmed that the method is efficient. Fig. 1 shows the algorithm flow.

![Fig. 1 The change detection algorithm flow](image-url)
3 Change Detection Based on DSM and Image Features

3.1 Potential changed areas acquired

It is well known that changes of man-made objects of urban area are certainly changes of real three-dimensional objects. A house is a typical three-dimensional object whose change will cause the height change of DSM. If we make use of the height information to detect the house change, it will do well for the improvement of the detection efficiency and performance. DSM contains the heights of objects and can be more quickly and conveniently generated on a digital photogrammetry workstation. Building the new and old DSMs will generate two DSM files of 1m resolution. Subtract the two DSMs to generate a new DSM file, which is called "difference DSM". The potential changed areas can be obtained by the following formulas:

\[ D(x, y) = N_{DSM}(x, y) - O_{DSM}(x, y) \]

where \( D(x, y) \) is the difference DSM; \( N_{DSM}(x, y) \) is the new DSM and \( O_{DSM}(x, y) \) is the old DSM.

By region growing and region merge, the potential changed areas in the difference DSM have been obtained. The potential areas in difference DSM will be transformed into the new and the old image (Fig. 2).

![Potential changed areas on the new image](image1)
(a) Potential changed areas on the new image

![Minimum rectangle of the potential changed areas](image2)
(b) Minimum rectangle of the potential changed areas

Fig. 2 Potential changed areas and their minimum rectangle

3.2 Analysis of the potential changed areas

Although the candidate changed areas had been found, whether they changed in fact and what kind of changes happened were not known. Some changes may be other kind of changes (e.g. sensor changes). It is well known that objects such as houses, trees, which are higher than the terrain surface, will be modeled as changes in DSM. It is necessary for further study to determine it. In order to detect the houses changed and reduce the false detection rate, we need to distinguish the areas which are the building region from others regions. Before further analysis, the following edge is performed in the candidate changed areas.

3.2.1 Method based on line-feature matching

The changed man-made objects are often related with houses and roads. The houses and roads usually present regular forms, and can be described with the line features. So by comparing the line features in the potential changed areas, the changes of man-made objects and other natural objects can be detected. A straight line can be determined by a pair of parameter \((\rho, \theta)\).

When the feature extraction procedure is finished in the candidate changed areas on both old/new images to be registered, a number of straight lines on the images are obtained.

Assuming the set of the straight lines in a candidate changed area of old image to be registered is

\[ O_{L} = \{(\rho_1, \theta_1), (\rho_2, \theta_2), \cdots, (\rho_m, \theta_m)\} \]
and the set of the straight lines in a candidate area of new image to be registered is

\[ N_L = \{ \rho_1, \theta_1, \rho_2, \theta_2, \ldots, \rho_n, \theta_n \} \quad (3) \]

and the distance between straight line \((\rho_i, \theta_i)\) in \(O_L\) and straight line \((\rho_j, \theta_j)\) in \(N_L\) is

\[ d_y = \sqrt{(\rho_i - \rho_j)^2 + (\theta_i - \theta_j)^2} \quad 1 \leq i \leq m, 1 \leq j \leq n \quad (4) \]

\[ S_y = \begin{cases} 0 & \text{if } \min(d_y) < \text{Thresh} \\ 1 & \text{else } \min(d_y) \geq \text{Thresh} \end{cases} \quad (5) \]

\[ C = \frac{\sum S_y}{(n+m) \times 100\%} \quad \text{if } S_y = 1 \quad 0 \leq C \leq 1 \quad (6) \]

where \(C = 0\) indicates that there is no non-matched straight line between \(O_L\) and \(N_L\); \(C = 1\), there are no matched straight line between \(O_L\) and \(N_L\), which means that the potential region changed. When the percent of matched straight lines \(C \geq \text{Thresh}\), the candidate areas should be a changed area, and it should be the change of the man-made objects. And \(S_y = 0\) shows that the straight line \(i\) in the set \(O_L\) is matched with the straight line \(j\) in the set \(N_L\), \(S_y = 1\), no straight line \(i\) in the set \(O_L\) is matched with the straight line \(j\) in the set \(N_L\).

In Fig. 3, the straight line pair in the old image is \(0\), but the line in the new image is \(4\), so the percent of matched straight lines \(C = 1\).

By using this method the potential changed region can further analyze whether man-made object changed. However, this method is strongly influenced by the result of the straight line detection. If the results are many, the computer cost for detecting the straight line will be very great. The determination of threshold \(C\) is difficult in the practical application. The experiment results are listed in Table 1.

![Fig. 3 Change detection of a potential region](image)

**Fig. 3** Change detection of a potential region

### 3.2.2 Method based on gradient direction histogram

In order to detect the changed houses and to reduce the false detection rate, we will analyze the potential changed region and distinguish the building regions from other objects.

Firstly, we define the gradient vector \(\vec{g}\) and gradient direction \(\alpha\) of the point \((x, y)\) on image \(f(x, y)\) as:

\[ \vec{g}(f(x,y)) = \left[ \frac{\partial f}{\partial x}, \frac{\partial f}{\partial y} \right]^T = [f_x, f_y] \quad (7) \]

\[ \alpha = \arctan\left(\frac{f_y}{f_x}\right) \times \frac{180}{\pi}, 0^\circ \leq \alpha \leq 360^\circ \quad (8) \]

As we know, different textures have different features\(^{[2]}\). In the gradient direction histogram of buildings (normalized to between \(0 \sim 360^\circ\)), there are usually four peaks representing four directions with internal \(90^\circ\), respectively, or there are two higher peaks with some lower peaks, whose internal is \(90^\circ\). In the gradient direction histogram of road (normalized to between \(0 \sim 360^\circ\)), there are only two peaks, and their interval is \(180^\circ\). However, in the gradient direction histogram of tree (normalized to between \(0 \sim 360^\circ\)), there is no distinct peak. We adopt this character to judge house from trees and roads.

In order to eliminate the disturbance of the interior point of areas and of the small peaks, the gradient direction histogram \(H(k)\) \(\left( 0^\circ \leq k \leq 360^\circ \right)\) is smoothed before the peaks are extracted.

A smoothed gradient direction histogram \(H(k)\) can be obtained by

\[ H(k)' = \frac{1}{(2w+1)\sum_{k=0}^{360}} H(k) \quad (9) \]

where \(w\) is a smooth window size, and in this paper, \(w = 5\) is the trade-off.

Fig. 4 shows the result of a smoothed gradi-
ent direction histogram.

Fig. 5 shows three different textures of the gradient direction histogram.

From Fig. 5, the histogram of the potential changed region of trees has no peak, that of roads has two peaks with the interval of 180°, but that of the buildings has four peaks with the interval of 90°.

![Gradient direction histograms of different textures](image)

We can distinguish the regions of trees and roads from those of buildings by this method. The potential changed region is the change of the building if the region gradient direction histogram have four peaks with the interval of 90°. The experimental results of this method are listed in Table 2. From the above analysis, this method can be automatically operated, and its efficiency is reliable.

4 Experimental Results and Analysis

4.1 Experimental results of acquisition of the potential changed areas

Firstly, the potential changed regions have been obtained by the height information. It is known that if there is no change in urban areas, the height information will change little. DSM can give the height information of region in the urban areas. So we established two stereo models for the two pairs of different periods, created two DSM files directly using the module in VirtuoZo, subtracted the two DSM to obtain the difference DSM and then extracted the potential changed areas from the difference DSM, which contains nearly 100% house changes and other changes. Fig. 6 shows the DSMs. From Fig. 6 (c), we can obtain the potential changed region. In the experimental images, the number of the potential change regions is 122, which will be analyzed by the method for further analysis.

![Old DSM, new DSM and difference DSM](image)
4.2 Results of analysis

These potential changed regions are obtained by the height information, so they may be tree or road regions. But our aims are to detect the change of buildings. In order to delete the regions of trees and roads, we will further analyze these changed areas.

In these potential changed regions, there are five possible cases (Fig. 7(a)-Fig. 7(e)).

We called the method of the line feature matching $M_L$, and the methods of the gradient direction histogram as $M_H$. Case 1 and Case 2 (Fig. 7(a), Fig. 7(b)) can not be affirmed by $M_L$, but they can be affirmed by $M_H$. Case 3 (Fig. 7(c)) can be affirmed by $M_L$ and $M_H$. Case 4 (Fig. 7(d)) can not be affirmed by $M_L$, but it can be affirmed by $M_H$. Case 5 (Fig. 7(e)) can not be affirmed by $M_L$ and $M_H$. In order to analyze Case 5, we adopt the method based on image matching.2.

In order to evaluate the further analysis method, we define the reliability as:

$$\text{Reliability} = \frac{\text{Correct}}{\text{Total}} \times 100\% = \frac{\text{Correct}}{(\text{Correct} + \text{Error})} \times 100\%$$

(10)

where Correct includes two parts: one is the real changed areas in changed areas, and the other is the real unchanged areas in unchanged areas.

In this paper, the method of image analysis is based on the results of analysis of DSM, and it combines the height information with texture information. In this way, there are 122 candidate regions detected by DSM comparison. After the line feature analysis, 77 regions are determined as changed regions, among which 54 regions are really changed. And 45 regions are determined as not changed, among which 30 regions are really
not changed. The reliability is \((54 + 30) ÷ 122 = 68.85\%\). It can also be analyzed in the following ways. The analysis of gradient direction is used in the combined candidate areas to confirm the changed regions. All together, 93 regions are determined as changed regions among which 66 regions are really changed, and 29 regions are determined as not changed among which 26 regions are really not changed. The reliability is \((66 + 26) ÷ 122 = 75.40\%\).

5 Conclusions

On the basis of spatial remote sensing images, the traditional methods of single image analysis in change detection can also be used based on aerial images. In this paper, the changed detection method is based on aerial image. It is useful to update UGIS timely and to improve rapidly the processing speed by the new method of change detection. The new method of stereo image analysis is also suitable for the change detection using aerial stereo image pairs, and it is simple, easy to operate.

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