Superpixel-Based 3D Building Model Refinement and Change Detection, Using VHR Stereo Satellite Imagery

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Abstract

Buildings are one of the main objects in urban remote sensing and photogrammetric computer vision applications using satellite data. In this paper a superpixel-based approach is presented to refine 3D building models from stereo satellite imagery. First, for each epoch in time, a multispectral very high resolution (VHR) satellite image is segmented using an efficient superpixel, called edge-based simple linear iterative clustering (ESLIC). The ESLIC algorithm segments the image utilizing the spectral and spatial information, as well as the statistical measures from the gray-level co-occurrence matrix (GLCM), simultaneously. Then the resulting superpixels are imposed on the corresponding 3D model of the scenes taken from each epoch. Since ESLIC has high capability of preserving edges in the image, normalized digital surface models (nDSMs) can be modified by averaging height values inside superpixels. These new normalized models for epoch 1 and epoch 2, are then used to detect the 3D change of each building in the scene.

1. Introduction

3D Digital Surface Model (DSM) derived from stereo satellite imagery, is an important result of matching techniques in photogrammetric computer vision, and also a main input data and source in many photogrammetry and remote sensing applications, like scene classification, object tracking and 3D change detection. Amongst those, urban remote sensing covers a wide range of topics including urban sprawl/growth modeling, population and pollution analysis, and traffic monitoring. Consequently, buildings and man made structures are of high importance, and a significant number of research on 3D model generation and refinement has been developed and reported. In this part we have a short review on the remarkable works in this field.

1.1. 3D model refinement

3D model generation from stereo satellite imagery, suffers from mismatching in the automatic image matching process and problems such as occlusions, shadows, radiometric artifacts, like specular reflections. Generally, the DSM refinement task includes two main steps; first, to fill the holes and no-data areas in the DSM to generate a seamless 3D model, known as void filling, and second, to remove or reduce edge uncertainties and errors mainly on object boundaries, usually known as DSM enhancement.

A majority of early reported approaches for void filling, use interpolation of no-data regions, alone or along with an auxiliary source [2]. However, with recent developments in multispectral image segmentation techniques, efficient methods for void filling have been developed, like our previous work [2] in which the void filling algorithm is applied using multispectral image segmentation followed by a region-based interpolation.

To reduce the uncertainties and enhance the DSM from VHR satellite imagery, a common method is to use semantic segmentation or classification results. For example, Krauß and Reinartz proposed an approach based on fusing the disparity map generated by the dense stereo matching with the image segmentation and classification results [6].

1.2. 3D change detection

Three-dimentional change detection is one of the main tasks in urban photogrammetry and remote sensing, which is essential for sustainable urban management, city monitoring and damage assessment after hazards and natural disasters. Therefore, many attempts have been done to estimate changes in a reliable way, using data from different sensors including satellite imagery. Generally, 3D change detection methods can be summarized into different categories depending on the target element to be inspected (i.e. pixel or object), or regarding the method of comparison (i.e. geometric or geometric-spectral) [8].

Although pixel-based geometric comparison approaches are simpler and more straightforward than the other methods, the uncertainties of 3D data may lead the algorithms to miss many true changes or render many artifacts in the resulting change map. Other approaches are developed utilizing feature fusion [9] and object detection/classification [7] to improve the robustness of change detection algorithms. These approaches achieve correct results in most areas, however still shortcomings appear due high dependency of 3D change detection approaches [9] to the DSM quality. As a result, an improvement in the quality of the 3D model can improve the final result of 3D change detection.

Here, our focus is to refine 3D building models derived from VHR stereo satellite imagery, and simultaneously detect 3D changes of single building from two epochs, using the state-of-the-art superpixel segmentation algorithm.

2. Methodology

In this study, first a DSM is generated from the stereo satellite images for each epoch. Both DSMs contains some inevitable artifacts especially around the buildings and on the object boundaries. Before being used for building 3D change detection, they should be refined. Figure 1 shows the work-flow of the proposed method. For each epoch, a 3D surface model can be effectively generated with Semi-Global Matching (SGM) algorithm, first proposed by Hirschmuller [5], and improved by [3] for satellite data. Vegetation extracted by the Normalized Difference Vegetation Index (NDVI), and shadows extracted from the corresponding pan-sharpened (PS) image, are then removed from the nDSM to create a coarse estimation of building locations, so that rough 3D building models are remaining.

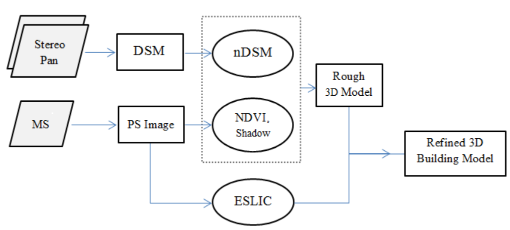

Figure 1. Work-flow of the proposed algorithm for 3D building models refinement.

To refine the building shapes both in 2D shape and in 3D height model, we propose an edge-based superpixel algorithm. The orthorectified multispectral image, corresponding to the DSM from each epoch, is segmented using a superpixel algorithm regarding the spectral information of object surfaces. The superpixels are imposed on the 3D model, and an average height value is assigned to the areas inside the DSM corresponding to the superpixels in the image. In this way, not only the artifacts around the buildings and man-made objects are eliminated by the surrounding background and non-building heights, but also the 2D building shapes are refined and the edges are becoming sharper and more realistic. Obviously the key factor of this step, is having an efficient superpixel segmentation to preserve the edges and building boundaries correctly.

2.1. Superpixel segmentation

ESLIC superpixel, proposed by Gharibbafghi *et al.* in our previous work [4], is a modified version of the SLIC superpixel algorithm [1], which is adapted to multispectral VHR satellite images to increase the boundary adherence of the resulting superpixels in urban scenes. ESLIC shows to outperform the SLIC algorithm in preserving weak boundaries in the image, as shown in Figure 2, due to the extra spectral and geometric features introduced to distance computation [4]. ESLIC is a localized iterative k-means algorithm, starting from a regular grid of seeds. For each seed point a neighborhood with size $2 \times S$ is defined, and the nearest neighboring pixels are labeled to be in the same superpixel. The distance measure, D in Equation 1, is calculated using spectral features, $d_{spectral}$, spatial Euclidean distance, d_{dist}, and statistical texture measure from GLCM, $d_{contrast}$, for a multispectral satellite image.

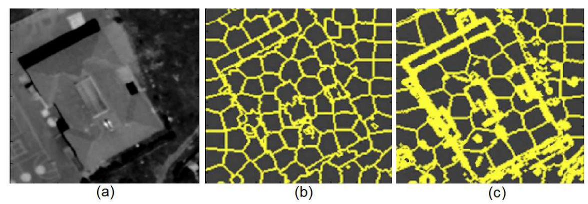

Figure 2. A sample building in a satellite image (a), superpixels resulting from SLIC (b), superpixels resulting from ESLIC (c).

$$D = \sqrt{(d_{spectral})^2 + (\frac{d_{dist}}{S})^2 m^2 + (d_{contrast})^2} \quad (1)$$

3. Experiment and results

We applied the method on a WorldView-2 dataset taken from Istanbul city, in two epochs, Figure 3. The refined nDSM, extracted from the first epoch is shown in Figure 4(c). Two profiles extracted from both original nDSMs and the refined one for epoch 1, are shown in Figure 4(1,2). As clearly can be seen, the 3D model of the scene is refined effectively, especially on the edges and building boundaries. For example, profile (1) shows that the three buildings which are attached in the original nDSM due to errors and artifacts, have been detached and detected as single buildings in the refined nDSM. Figure 3(c) shows the result of pixel-based change map extracted from the refined nDSMs. We used the groundtruth to evaluate our change map re-

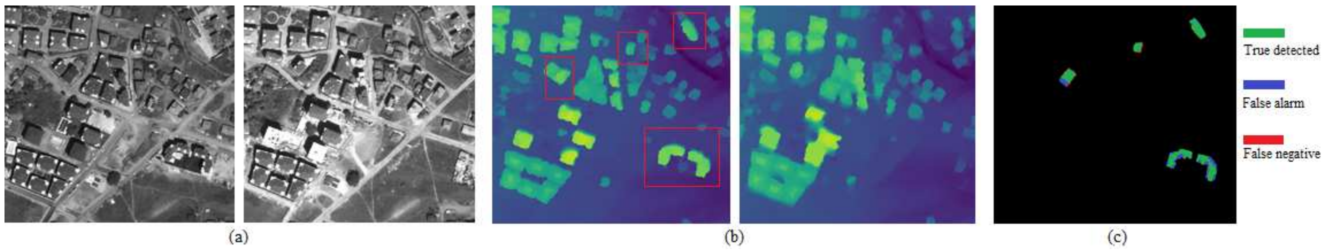

Figure 3. Input WorldView-2 dataset, panchromatic images (a) and DSMs (b) in two epochs. Final change detection results (c).

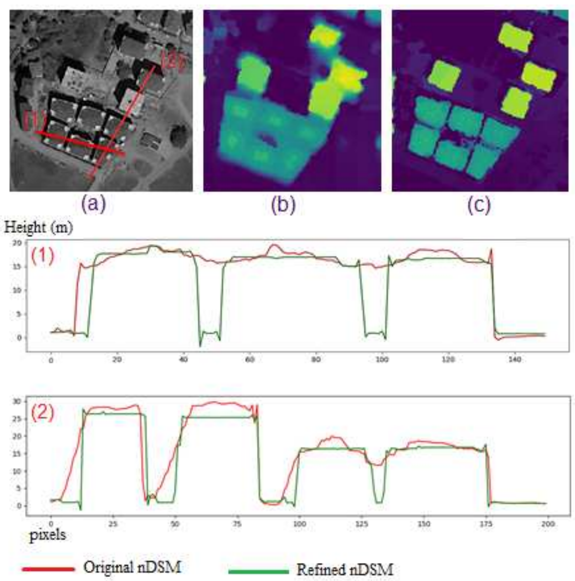

Figure 4. Top: Pan image (a), the corresponding DSM (b) and our refined 2D building shapes (c). Bottom: Profiles from both original nDSM and the refined nDSM.

sult. Based on true positive, true negative, false negative, and false positive measures , the Kappa Index of Agreement (KIA) [9] was calculated (KIA = 0.79), which indicates an improvement compared to the reported result in [10] for the same dataset (KIA = 0.77).

4. Conclusion

In this paper a novel superpixel segmentation algorithm, ESLIC, is utilized for 3D building model refinement using VHR satellite imagery. The refined 3D models in two epochs are then used for 3D change detection. ESLIC is a simple, fast and efficient way of superpixel segmentation that can preserve the building boundaries in complex urban scenes. Imposing ESLIC superpixels from multispectral satellite image on the corresponding registered nDSM, followed by averaging height values inside each superpixel, leads to a refined 3D model. Since the building edges in the new nDSM become sharper and the artifacts around the buildings are eliminated, building shapes are closer to the real shape. In this way, for each epoch single building models are extracted from the refined nDSM. Consequently, even a simple pixel-based height comparison of the two 3D model can be used for 3D change estimation of buildings.

References

[1] R. Achanta, A. Shaji, K. Smith, A. Lucchi, P. Fua, and S. Süsstrunk. Slic superpixels. Technical report, 2010.

[2] Z. G. Bafghi, J. Tian, P. d'Angelo, and P. Reinartz. A new algorithm for void filling in a dsm from stereo satellite images in urban areas. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 3:55, 2016.

[3] P. dAngelo. Improving semi-global matching: cost aggregation and confidence measure. *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 41:B1, 2016.

[4] Z. Gharibbafghi, J. Tian, and P. Reinartz. Modified superpixel segmentation for digital surface model refinement and building extraction from satellite stereo imagery. *Remote Sensing*, 10(11):1824, 2018.

[5] H. Hirschmuller. Stereo processing by semiglobal matching and mutual information. *IEEE Transactions on pattern analysis and machine intelligence*, 30(2):328–341, 2008.

[6] T. Krauß and P. Reinartz. Enhancement of dense urban digital surface models from vhr optical satellite stereo data by pre-segmentation and object detection. *Int Arch Photogramm Remote Sens Spat Inf Sci XXXVIII (Part 1), on CDROM*, 2010.

[7] R. Qin, X. Huang, A. Gruen, and G. Schmitt. Object-based 3-d building change detection on multitemporal stereo images. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 8(5):2125–2137, 2015.

[8] R. Qin, J. Tian, and P. Reinartz. 3d change detection–approaches and applications. *ISPRS Journal of Photogrammetry and Remote Sensing*, 122:41–56, 2016.

[9] J. Tian and J. Dezert. Fusion of multispectral imagery and dsms for building change detection using belief functions and reliabilities. *International Journal of Image and Data Fusion*, 10(1):1–27, 2019.

[10] J. Tian, L. Metzlaff, P. d'Angelo, and P. Reinartz. Region-based building rooftop extraction and change detection. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, 42, 2017.