Extracting Accurate Building Information from Off-Nadir VHR Images

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1. Introduction

Since buildings are the most prominent class in urban areas, updated building information plays an important role in urban planning and management applications. The most cost-effective and broadly available geo-data for mapping building information is the very high resolution (VHR) satellite images. Thus, building detection in VHR images has been an active research area for the remote sensing community during the last two decades (Doxani, Karantzalos, and Tsakiri-Strati 2015; Khosravi, Momeni, and Rahnemoonfar 2014).

VHR optical images are the 2D perspective projection of the real surface. Hence, they lack the elevation information. Since buildings are elevated objects, image and elevation data co-registration is required for accurate and reliable detection results. However, several problems are introduced when such data types are integrated (Dowman 2004).

Elevation data are typically generated by the photogrammetric approaches and LiDAR (light detection and ranging) technology. Both of these sources provide the height information of the tops of surfaces such as buildings or trees. Hence, they result in digital surface models (DSMs). DSMs are generated as an orthographic projection (nadir view), while VHR images are usually acquired as perspective projections with across-track/along-track angle (off-nadir view). This projection difference makes accurate co-registration very difficult to achieve.

The co-registering methods of image and elevation data are extensively reviewed in our previous work (Suliman and Zhang 2015). In that work, we introduced the line-of-sight DSM (LoS-DSM) solution to overcome most of the limitations in the reviewed methods and provide pixel-by-pixel co-registration. In our recent work, some modifications have been made to the original algorithm where an improved efficient algorithm based on disparity information has been developed (Suliman and Zhang 2016).

In this study, we demonstrate the applicability of the recently developed disparity-based LoS-DSM solution for building detection in off-nadir VHR satellite images using stereo-based elevation data. The elevation data generated by the improved algorithm are of minimized terrain-relief effects. Hence, the need for calculating the aboveground building heights should be reduced in the dense urban areas that are characterized by moderate terrain-relief variations.

This paper is organized as follows: the proposed method is briefly described in Section 2, the optical data and the achieved results are provided in Section 3, and finally the conclusions are drawn in Section 4.

2. The Proposed Method

The method proposed is flowcharted in Figure 1. The method has four steps that are described as follows:

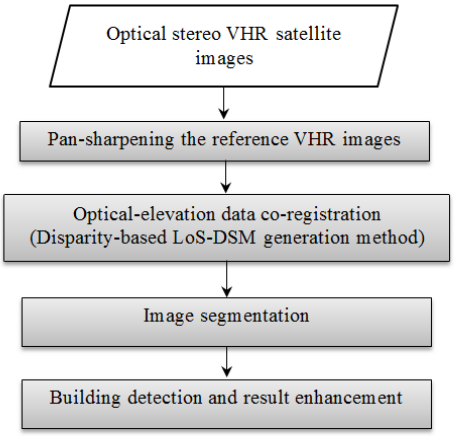


Figure 1. Flowchart for the proposed building detection method.

(1) Image Pan-sharpening
VHR images are acquired with panchromatic and multispectral bands. Since the ground resolution of the multispectral bands is one-fourth of that for the panchromatic one, these bands need to be pan-sharpened to improve the segmentation and detection results. The UNB pan-sharpening technique introduced by Zhang (2004) is selected for this step.
(2) Disparity-based LoS-DSM Generation
To achieve accurate and efficient image-elevation co-registration and minimizing the terrain-relief effects for the generated stereo-based elevation data, the disparity-based LoS-DSM generation algorithm is selected to be executed. The algorithm is described in our recent work (Suliman and Zhang 2016).
(3) Image Segmentation
To reduce the complexity of the reference VHR image, an image segmentation technique should be used. We propose the use of the multi-resolution image segmentation technique introduced by Baatz and Schäpe (2000) since it has proven as one of the most appropriate techniques for segmenting VHR images in urban areas.
(4) Building Detection and Enhancement
Since the improved LoS-DSM algorithm minimizes the terrain-relief variations, a direct threshold can be applied to detect the off-terrain objects. However, trees and building façades will also be included in this detection, and hence they should be removed.
Fortunately, tree objects can be detected by vegetation indexes. Thus, the Normalized Difference Vegetation Index (NDVI) is selected. The results will still suffer from occlusion due to building façades. Visibility checks for occlusion detection are reviewed by Egnal and Wildes (2002). Accordingly, the left-Right visibility check is selected in this study for generating an occlusion mask to detect and remove the building façades. In addition to the NDVI and occlusion masks, a few morphological operations can be applied to enhance the detection result.

3. Data and Results

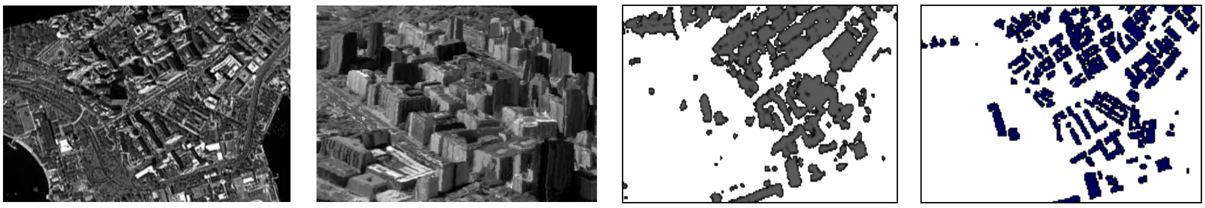
The dataset used for this research is a subset of VHR multi-view stereo images that are acquired by the linear array sensor of the WorldView-2 satellite. These images are acquired off-nadir over a dense urban area in Rio de Janeiro, Brazil (2010). Figure 2(a) illustrates the off-nadir VHR reference image.

Following the steps identified in the previous section, the reference image was first pan-sharpened using the UNB fusion technique. This step allows using the spectral information in the removal of vegetation, as well as producing a better segmentation result. Afterwards, the disparity-based LoS-DSM generation algorithm was executed. This algorithm guaranteed achieving accurate co-registration of image and elevation data. A visual inspection confirmed the successful achievement of accurate co-registration, as shown in Figure 2(b).

Next to this result, the pan-sharpened scene was segmented using the multiresolution image segmentation technique. The off-terrain segments were thresholded based on an elevation value close to zero. This is due to the remarkable terrain-relief minimization achieved in the improved algorithm. The un-enhanced detection result is presented in Figure 2(c).

To enhance the building map, two masks were generated: the vegetation mask and occlusion mask. The vegetation mask was generated by thresholding NDVI values calculated based on the pan-sharpened scene, while the occlusion mask was generated based on the left-Right visibility check. After applying these two masks and executing some finishing operations, the final enhanced building detection map was achieved as shown in Figure 2(d).

To evaluate the accuracy of the building detection result, the typical performance evaluation measures for building detection methods were used. These measures are described and used in Suliman and Zhang (2015). Based on these measures, the overall quality measure was found to be more than 90% relative to manually generated reference data. The detection result was almost 95% complete and correct.



(a) (b) (c) (d)

Figure 2. Data used in the test and the achieved results. (a) Reference VHR image, (b) isometric rendered view showing the quality of image-elevation data co-registration, (c) off-terrain level objects detected, and (d) the final enhanced building detection map.

4. Conclusions

This research demonstrates the applicability of the improved algorithm for generating LoS-DSM elevation data through an elevation-based building detection in off-nadir VHR satellite imagery acquired over a dense urban area.

The improved LoS-DSM algorithm was executed over a test dataset. The achieved image-elevation co-registration was very successful based on a visual assessment. Then, the generated and co-registered elevation data were applied in elevation-based building detection. The achieved building map was enhanced based on vegetation and occlusion masks as well as some morphological operations. The quality of the detection was evaluated based on manually generated reference data. The overall detection quality was found to be more than 90% with almost 95% of complete and correct detection. This level of performance in such a challenging dense urban area proves the high success of the disparity-based image-data co-registration as well as the applicability of the developed LoS-DSM elevations to detecting building objects even in off-nadir VHR satellite images acquired over dense urban areas.

We have noticed that the generated vegetation index may produce inaccurate results in the cases of roof gardens and buildings with high NDVI values. Thus, our future work will address this type of limitation.

Acknowledgements

This research is funded in part by the Libyan Ministry of Higher Education and Research (LMHER) and the Canadian Research Chair (CRC) program. The optical data used in this research are provided by Digital Globe for the IEEE-IGARSS 2011's Data Fusion Contest.

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