COMPARISON OF ESTIMATED BUILDING STORY NUMBER FOR EXPOSURE MAPPING FROM HIGH RESOLUTION SPACE-BORNE IMAGES

Gholam Reza Dini [1,2(*)], Gianni Lisini [1], Mostapha Harb[1], Paolo Gamba [1]

[1]Department of Electronic Engineering, University of Pavia, Italy
[2] Institute of Photogrammetry and Geoinformation (IPI), Leibniz University Hannover, Germany
[(*)] Corresponding author: Tel. +39-0382-985923, Fax: +39-0382-422583
E-mail: dini@ipi.uni-hannover.de

ABSTRACT

In this paper, two different approaches are proposed for the estimation of building footprints and number of stories using high resolution space-borne images. To this aim, semi-global matching (SGM) is used to generate normalized digital surface models (nDSM) from stereo pairs. Alternatively, a height-from-shadow approach (called "shadow-raiser") is implemented by detecting building rooftops and related shadow regions. Using associated lengths of shadow, the building heights are computed based on sun elevation and azimuth. The results of the proposed algorithms using IKONOS and GeoEye images demonstrate promising results with SGM, although the building dimensions are usually overestimated. In contrast, shadow-raiser delivers good results only if the building-shadow pair is correctly detected. Moreover, it suffers from an overestimation for building height if shadow areas are mixed up with occluded areas, vegetation or roads.

Index Terms- Building, stereo image, shadow, image matching, IKONOS, GeoEye

1. INTRODUCTION

In the context of risk management, exposure is the human-behavior component of risk where the most effective intervention policies can be applied. UNIISDR defines exposure as: people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses [1]. Buildings of a metropolitan are the optimal specimen for exposure monitoring as they present the geographical spreading of the community essential values: individuals and their livelihood. Proper risk management imposes creating reliable tool for mapping, monitoring, and modeling the temporally and spatially changing distribution of the exposed elements. The proper metric for pertaining sustainable development of a community can be observed in a controlled urban sprawling. Remote sensing technology with its characteristics of broad cover, fast and relatively cheap data acquisition provides a suitable option for tracking geo information changes in general and of exposure, our risk element of interest, in particular. The continuous development of space bone products of high resolution optical sensors has enabled the extraction of more accurate geo information especially on buildings. For instance, the progress of the capabilities has developed from recognizing the urban areas from low-to-medium resolution sensors to extracting more detailed buildings characteristics from high resolution sensors, like buildings footprints and heights.

This paper focuses on extracting buildings' number of stories as a subsequent of extracting building footprints. The building floor number is an important indicator for different elements of risk like exposure and vulnerability. On one hand this indicator is an attribute of widely used building taxonomies (like PAGER, GEM…) due to its direct relation to the structural failure in extreme events. On the other hand it adds a value to the statistical data in estimating the population density and the occupation area per inhabitant in a region. These outcomes are of particular importance in areas of access difficulty, data scarcity, budget limitation, and of in urban areas where population densities increase is due to buildings height rise instead of built-up area extension.

In previous works, building change as well as building outlines were detected from high resolution satellite images by applying stereo image matching and 3D edge matching techniques, respectively [2,3]. In this paper, we compare the building height and associated number of stories derived from an photogrammetric image matching technique (stereo image) against a shadow-based (single image) approach.

2. HEIGHT ESTIMATION ALGORITHMS

Height estimation from satellite images requires either a stereo pair (if stereo matching approaches are considered) or a single image, for instance using height-from-shadow techniques. The two solutions are here briefly proposed and their results are discussed with respect to the definition of the number of stories, as oppose to the pure height in meters, to understand if the simplicity of the single-image approach does not degrade the performance of exposure mapping algorithms as much as it does when looking at the original height values.

2.1. Stereo Image Matching

There have been developed different methods for image matching in order to reconstruct depth using stereo pairs. Generally, there are two main methodologies for image matching; window-based methods those find the corresponding pixels between stereo pairs by using a template known also as *local methods,* the second approach is pixel-based which is called *global methods*. The drawback of first group is finding an optimum size of template size as well as local ambiguous areas (e.g. occlusion, shadow and poor textured areas such as asphalt). In contrast, global methods minimize the energy function in order to find the best corresponding matching. These methods are considerably robust against illumination and imaging direction however they usually need comparatively a rigorous computation.

Comparing the different matching methods in urban areas has revealed that the recently developed Semi-Global Matching (SGM) could generate promising DSM with the best accuracy quantitatively as well as by keeping the building shape qualitatively [4,5]. To estimate the relative height in pixel level, it is required to find corresponding pixel in both stereo images and then compute the parallax for each pixel stemming from object height. SGM as a pixel-wise image matching method requires epipolar image in order to reduce the search space in one dimension (x). Semi-global matching uses a well-efficient cost function to find corresponding pixel by searching all neighbor pixels. Then cost function is aggregated in 4-16 directions around epipolar lines. After calculation of cost aggregation, the disparity (D) is selected for each pixels by choosing the disparity that corresponds to the minimum cost. Finally, by elimination of outliers, the disparity is refined [5], and it is converted to DSM.

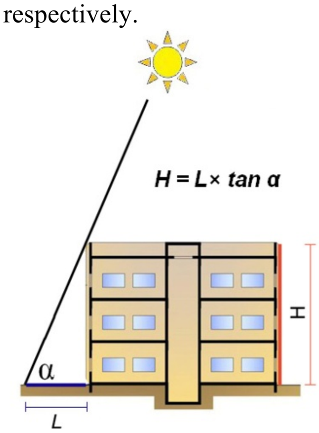
2.2. Shadow-Raiser Algorithm

The second approach analyzed in this research work estimates building height based on single images. As shown in figure 1, the idea is based on the knowledge of the acquisition geometry and specifically the viewing angle, sun azimuth and sun elevation. The viewing angle and sun elevation angle have an inverse relationship with the shadow length, and nadir observation in the central hours of the day is the worst case, while being the best one for the previous technique. Additionally, for a reliable estimation of building height using shadows, an accurate mapping of shadow length is very important, because miss-detection or overestimation of shadow class can miss or increase the associate building height significantly.

3. ALGORITHM IMPLEMENTATION

3.1. Building Recognition using SGM

For the detection of building footprints using SGM, we first filter the extracted DSM to derive a digital elevation model (DEM), and then subtract the DEM from the DSM, resulting in an nDSM. A threshold of 2.5m is applied and pixels with absolute values larger than 2.5m are considered as initial building blobs. Then, a morphological opening with a structuring element of four pixels is performed to discard very small blobs, which cannot possibly represent a building. The parameters are selected empirically based on the usual building size in the study area, hence we have applied 50m^2 and 4m as minimum size and width of building blobs, respectively.



Fig, 1: Building height estimation using the shadow length.

3.2. Building Height Estimation using Shadow-Raiser

To estimate building height using shadow length, first it is required to detect shadow region of interest and the associated building rooftop by using a classifier. Before that, however, one of the stereo pair image must be selected on the basis upon containing longer shadow length, and then individual buildings are extracted form the classification using building analysis routines develop at the University of Pavia [6]. Shadows and associated buildings are converted to binary maps. These maps and the image acquisition information (provided by spaceborne image metadata) are provided as input to the shadow raiser routine to compute the height for each individual building.

4. EXPERIMENTAL RESULTS

4.1. Test area

Our experiments are carried out using small subset from Riyadh, the capital city of Saudi Arabia. The dataset are pan-sharpened RGB stereo image pairs from IKONOS and GeoEye-1 acquired on May 24, 2008 and Sept. 15, 2009 with ground sampling distances (GSD) of 1m and 50cm, respectively. Semi-global matching (SGM) is used to find corresponding pixels and to compute the associated disparity map. Image orientation and DSM georeferencing were then computed on the basis of rational polynomial coefficients (RPC) without ground control point (GCP).

4.2. Building Footprints and Story Number Estimation

As mentioned above, building footprints are mandatory to extract building heights and eventually their approximated number of stories. For SGM buildings are identified as clusters of points higher than 2.5 m over the ground level (see fig. 3).

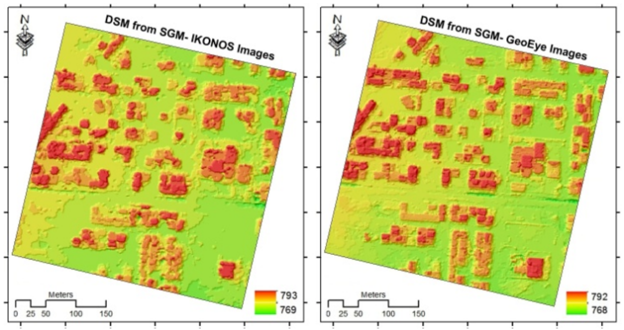


Fig. 2: DSM derived by SGM and based on an IKONOS (left) or GeoEye (right) stereo pair.

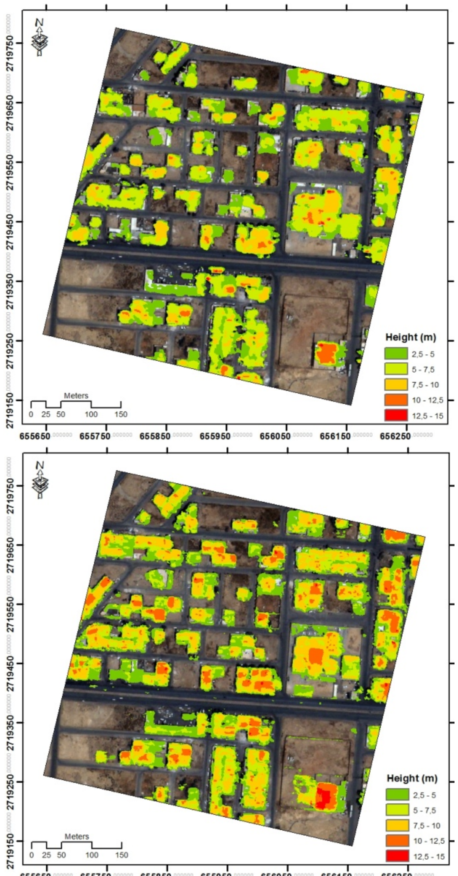


Fig. 3: Building blobs detection from (upper) IKONOS or (bottom) GeoEye nDSM.

As 3D edge matching was not an efficient solution to delineate all building outlines [3], in this study footprint are manually extracted. Building heights are then computed as the average value in each cluster. Finally, from building heights, and assuming that each story has an height of 2.5m, the number of stories for each building can be estimated, allowing to obtain a map (see fig. 4) where buildings are colored according to this value ranging from single-story (green) to five-story (red) buildings. Please note that the building size on DSM derived from image matching is normally larger than the real size. It is because of the smoothing effect as recognized in [2,3].

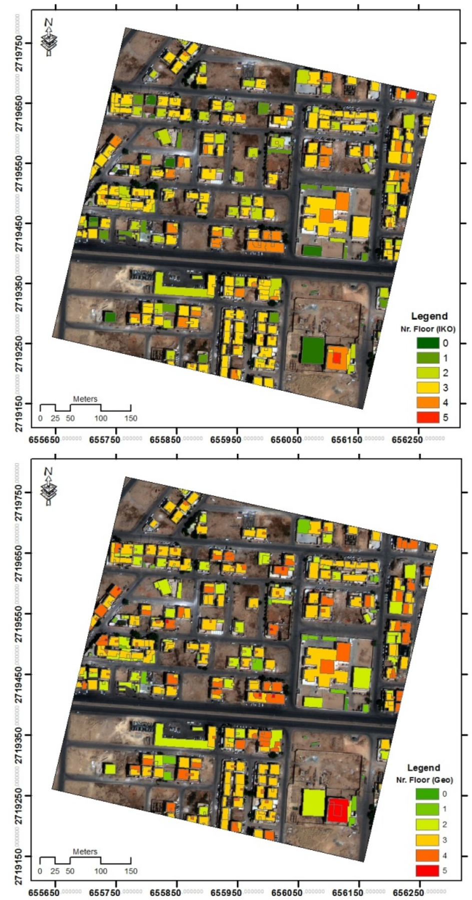


Fig. 4: Estimation of the number of stories using (upper) IKONOS or (bottom) GeoEye nDSM.

To detect buildings and then compute their height from their shadows we first need a classifier. In our experiments we used a simple maximum likelihood classification (MLC) and classified the spaceborne image according to five classes: shadows, buildings with bright roof, buildings with dark roof, vegetation and roads/parking lots. Clusters of pixels belonging to the two building classes, together with the associated shadows, are then used to extract an approximation of the building height. Eventually, this value is assigned to each building polygon as depicted in Fig. 5.

Unfortunately, there is no ground truth data for the study area. Even Google Earth™ and ©MS-Bing Maps provide no oblique-view or street-view image in order to recognize the actual number of stories. However, previous studies have revealed that the DSM derived using SGM from spaceborne images has shown an RMSE around one meter [4]. Therefore, we may assume that the SGM data are close to the actual values, and compare the number of stories obtained from shadows to these numbers

In Fig. 6, the histograms of the values obtained subtracting the number of stories extracted using the shadows from those obtained by SGM starting from GeoEye and IKONOS stereo pairs. The largest part of the detected difference are within 2 or 3 stories, which is a negligible result from the point of view of building vulnerability and exposure, if the buildings are above 3 to 4 story high. In this test site, however, many of the building are single story buildings, and this difference is significant.

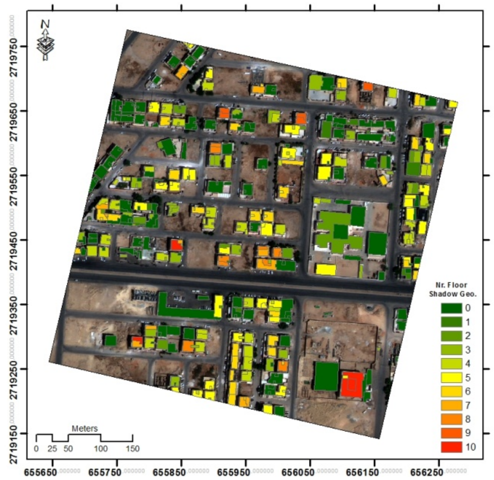


Fig.5: Estimation of the number of building floor based on shadow-raiser approach using one of the images of the GeoEye stereo pair.

From the point of view of height extraction, the histograms stress two main findings. First, the median value is negative, corresponding to an overestimate of the buildings in average of around 4.5m as it is also reported in [7]. The second point is that there is some bias in the shadow-based extraction mainly due to height overestimation. In contrast, if we ignore new constructions, the height difference in the third histogram of fig. 6, representing the different in story number between the two SGM extractions, shows a typical Gaussian distribution, indicating there are no significant miss-detections or overestimations. Furthermore, the median is equal to 1.55, with this offset mainly due to new constructions in 2009 compared to previous DSM derived from IKONOS in 2008 (see [2] for further explanations).

5. DISCUSSION AND CONCLUSIONS

As shown in experimental results, individual buildings extracted from the SGM DSM have footprints less regular than their actual ones. Instead, the output of the classification and footprint regularization approach is more precise, showing that the shadow-based analysis is more accurate. On the contrary, the other relevant input to vulnerability models, i.e. the number of stories, is better captured by the SGM method.

As for the data, it can be concluded that while the stereo pairs for Riyadh are appropriate from the photogrammetric viewpoint to generate DSM, they are inappropriate for building story estimate using shadows, as the images are taken near to nadir point and show very small shadows.

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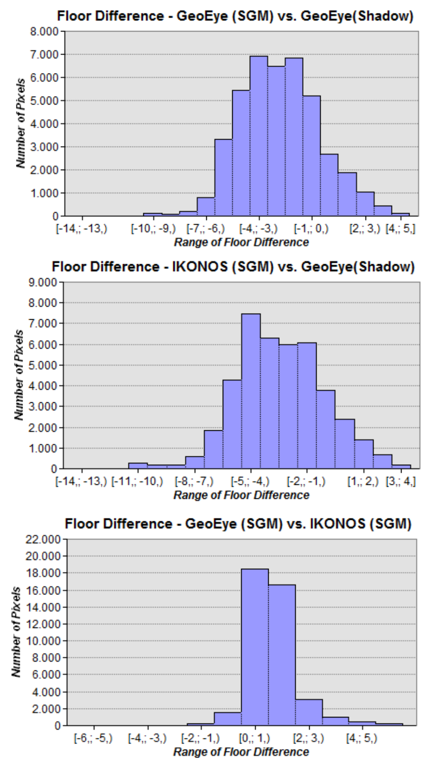

Fig. 6: Histogram of building height differences.

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