Detecting changes between a DSM and a high resolution SAR image with the support of simulation based separation of urban scenes

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Abstract

As a SAR image is often the only available data in crisis situations, e.g. after an earthquake, a change analysis of the SAR image with previously acquired data may enable a fast analysis of the damage caused by the disaster. This paper presents a method for change analysis of the simulated appearance of a digital surface model (DSM) and a SAR image. A simulated SAR image is generated using the DSM and is separated into four masks indicating double bounce reflection, layover, shadow areas and ground reflection. Temporal changes of the corresponding areas in the real SAR image are analysed using pixel-based methods. Finally, the change detection results for the four masks are combined in order to obtain a robust change analysis result for single buildings. In this regard, the application of the proposed concept is presented for the city centre of Munich using TerraSAR-X data.

1 Introduction

Due to the all-weather and all-time data acquisition capability, SAR images are often the only available data in crisis situations, e.g. shortly after an earthquake. Having one pre-event and one post-event very high resolution (VHR) SAR image, changes within the scene of interest can be recovered [1] [2]. However, the change analysis may be hampered by different SAR imaging geometries, missing pre-event SAR data, and the revisit time related to subsequent SAR acquisitions. Including a-priori information from other data sources may be helpful in order to resolve some of the limitations, e.g. using optical data [3].

For some urban areas, digital surface models (DSM) are available in advance to the disaster, e.g. derived from high resolution airborne optical imagery or LiDAR data. Detecting major changes between the simulated appearance of a DSM on a SAR image and a post-event SAR image may enable an approximate but fast analysis of the damage caused by the disaster within the urban area if only a post-event SAR image is available.

In this paper, simulation methods are applied in order to provide separate image layers focusing on different parts of an urban scene. In more detail, we use specific properties of the simulation technique in order to generate four image masks indicating double bounce reflection, layover, shadow and ground areas. Thereafter, image layers are used for a combined change analysis of a real SAR image. Eventually, the results of the four masks are combined in order to identify positive and negative changes.

2 Separation of the simulated image

2.1 Generation and geocoding of the simulated SAR image

The basis product for analyzing the VHR SAR image (geocoded TerraSAR-X image captured in spotlight mode) for changes is a co-registered and geocoded simulated image. First, we apply our SAR simulator named RaySAR [4] to generate a simulated SAR image using a LiDAR DSM. Thereafter, we use the geoinformation of the DSM, the orbit and image parameters of the real SAR image and a line extraction and matching algorithm to geocode and co-register the simulated image. A detailed description of the generation and geocoding of a simulated SAR image using a DSM is given in [5-7].

2.2 Simulation of separate layers

We exploit the ray tracing concept of the simulation technique for separating the simulated SAR image into different image parts. In the end, four types of layers are distinguished in our method: double bounce reflections, layover, shadow and ground areas.

Simulated signals of reflection levels 1 and 2 are assigned to separate image layers [4]. We convert the reflection level 2 to a binary map which, after geocoding, indicates the location of the double bounce lines on the TerraSAR-X image.

For extracting the layover mask, we generate a normalized digital surface model (nDSM) from the digital surface model. Using the same simulation parameters as for the DSM, a simulated image of the nDSM is generated. The converted binary map of this image indicates reflected signals from buildings (layover area).

The shadow mask is generated by finding pixels with zero intensity on the simulated image of the DSM. Eventually, the difference of the two simulated images for the DSM and nDSM indicate the influence areas of ground pixels presented in the DSM.

3 Simulation-based change detection

As the simulated and real SAR images are already co-registered, the masks extracted from the simulated images are used directly for identifying areas on the real SAR image. Afterward, we analyse the corresponding pixels within the areas on the real SAR image. Note, that we do not compare the radiometry of the simulated image to the real SAR image, because the intensity of the simulated image has no physical meaning and, hence, is of limited value. Instead, we exploit the geometric information provided by the simulated image, e.g. the shape of the extracted masks.

Different types of changes lead to different effects on different image layers. This is detailed in Table 1. If we rate the intensity of different layers in four levels (0-3 indicates low to high), a positive change can be only seen in ground and shadow areas (marked in green), while a negative change can be identified in double bounce, layover and shadow areas (marked in red).

TABLE 1. Effect of positive and negative change for different layers

Layers	Intensity class	Intensity class after -	
		positive change	negative change
Double bounce	3	3	1
Layover area	2	2	1
Ground area	1	2	1
Shadow area	0	2	1

3.1 Change detection using simulation results of whole DSM

The aim of this step is to provide a rough change result for a city part, i.e. candidate areas for a refinement step which follows afterward. To this end, a pixel based algorithm is performed to detect positive changes of large extent in shadow and ground areas. Based on experimental results, an intensity threshold is determined by a statistical analysis of the whole SAR image, what is done for each image layer. All pixels in the corresponding layer in the SAR image are compared to this threshold value and are then classified to 'change' and 'no change' according to Table 2. The detailed steps are described in [5].

Exploiting the layover and double bounce layers, we tried the same method based on the assumption that low intensity pixels indicate negative changes. However, the reflection of the radar signals depends on many different physical parameters (e.g. material, roughness), which may be only roughly considered in the simulation step and are not provided by the LIDAR DSM. Moreover, due to the lack of geometrical information in the 2.5D DEM, no facade signal can be simulated in order to predict the appearance of salient signatures. To conclude, the amount of a-priori knowledge provided by the DEM does not suffice for a generalized pixel-based analysis for negative changes, as there are many "false alarms" in the change detection result (also in case of a significant reduction of spatial resolution). Hence, object information has to be included in addition to the 2.5D DEM, e.g. facade grammar characterizing buildings in the local scene of interest.

TABLE 2. Pixel based change analysis of the real SAR image

Mask	No change	change
Double bounce	> Threshold	< Threshold
Layover area	> Threshold	< Threshold
Ground area	< Threshold	> Threshold
Shadow area	< Threshold	> Threshold

3.2 Detection of changes for individual buildings

The changes of large scale detected for the full urban scene (see 3.1.) are taken as "change candidates" and are analyzed in more detail.

Firstly, all building complexes near change candidate areas are extracted from the nDSM. Thereafter, they are used as input in RaySAR in order to generate three layers (layover, shadow and double bounce) for each building using the simulation method described in 2.2.

Eventually, we combine the results of the three masks for each building in order to increase the robustness of the changes decision. The time cost of the simulation and generation of layers for a single building model is approximately 8 seconds, giving the opportunity to analyze buildings individually for a city part within a limited amount of time.

If both the shadow and layover image parts indicate a "change", the building has been rebuilt.

4 Experimental results

For the simulation, we use a LiDAR DSM (1250*900 pixels) of the Munich city centre with a vertical and horizontal resolution of 0.1 meter and 1 meter, respectively. Moreover, a DEM with a single building model in Munich has been generated. Both model scenes are shown in Figure 1.

The real TSX image (spotlight mode, GEC product, taken at 2008.06.07, incidence angle 50°, descending orbit) and the co-registered and geocoded simulated SAR image are shown in Figure 2.

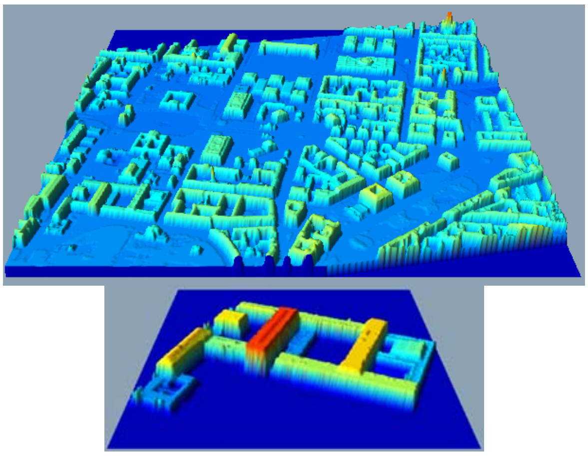
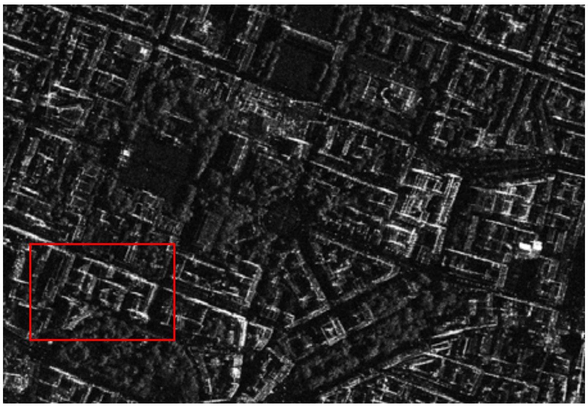
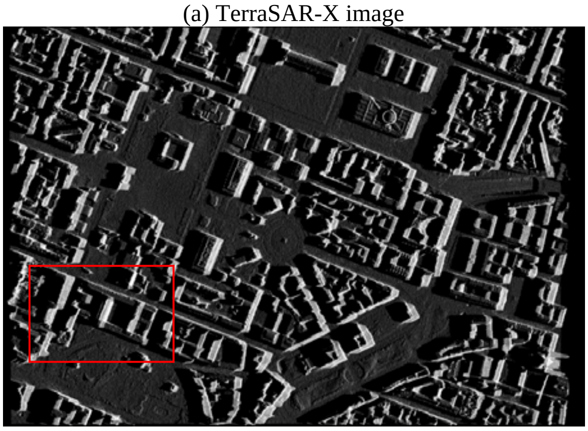


Figure 1. Digital surface model of Munich centre (upper), digital elevation model with a single building model (lower)



(a) TerraSAR-X image



(b) Simulated image

Figure 2. TerraSAR-X GEC product (top) and the coregistered geocoded simulated SAR image (bottom) of Munich city centre

The different layers (shadow, ground, layover and double bounce), generated from the simulation results, are indicated by different colours in Figure 3.

The TSX image is converted to a logarithmical intensity scale. The logarithmical histograms of the different layers are shown in Figure 4.

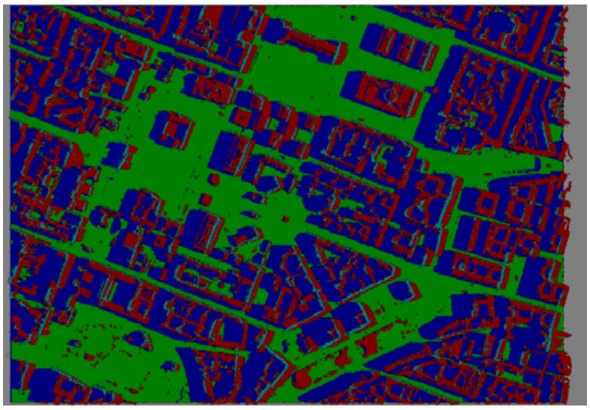


Figure 3. Different layers from simulation results, rate in the image (grey: no value 1%; blue: shadow 35%; green: ground 28%; red: layover 29%; cyan: double bounce 7%)

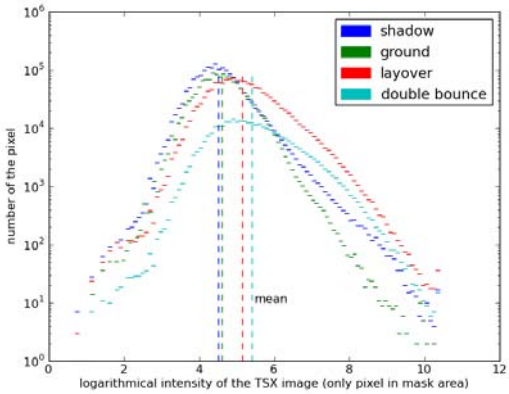


Figure 4. Logarithmical histogram of different layers in the TSX image (logarithmical intensity)

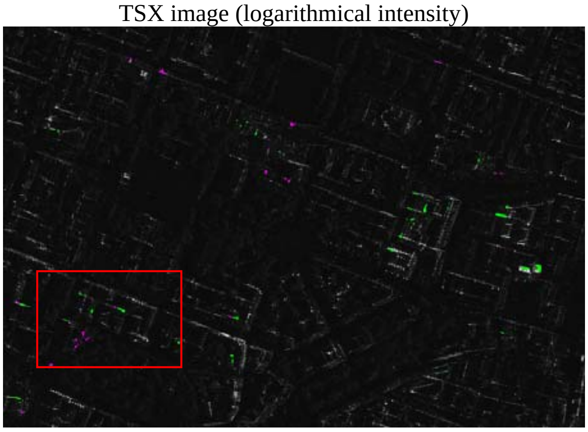
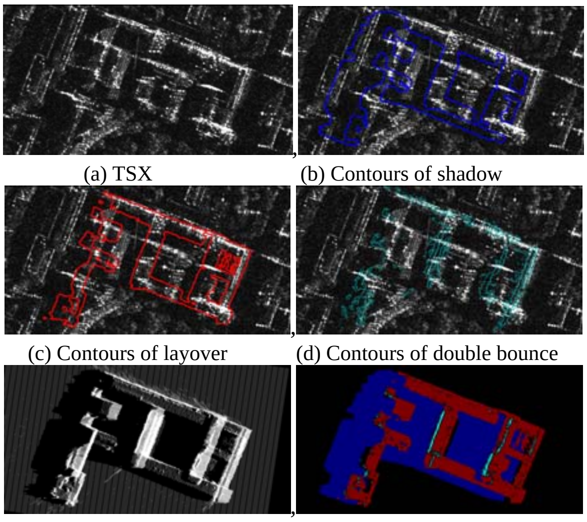


Figure 5. Change Results by analysis of shadow (cyan) and ground areas (magenta), overlaid on scaled TSX image

After thresholding and median filtering, the change analysis of the shadow and ground layers in the TSX image indicate candidates for negative changes, which are marked in green and magenta in the Figure

5, respectively. Compared visually to the images seen in Figure 2, this result is reasonable.

After the analysis of the full urban scene in the TSX image based on shadow and ground masks, single buildings near the candidate areas are extracted and are simulated. As an example, a building in the lower left corner of the image (rectangle marked) is chosen and is analyzed in detail. Figure 6 shows the simulated image and the generated mask for shadow, layover and double bounce reflections. The contours of the masks are overlayed on the TSX image. As all contours show shapes which are different to the building appearance in the TSX image, the conclusion is that the building has been rebuilt.



(a) TSX (b) Contours of shadow (c) Contours of layover (d) Contours of double bounce (e) Simulated image (f) Generated masks

Figure 6. Simulation results for a single building

5 Conclusion

In this paper, a change detection method is presented which uses a simulation technique to detect negative and positive changes between a DSM and a high resolution TerraSAR-X image. Exploiting simulated images from the DSM and nDSM, four image masks are generated, indicating double bounce reflection, layover, shadow and ground areas. Rough positive changes are detected by analyzing the corresponding masks in the TSX image. Using this change result, single buildings near the candidate change areas are then analyzed in detail for refining the detection result.

The experimental study shows that a pixel-based analysis using the shadow and ground masks may provide strong hints to positive changes. For negative change detection in layover masks, feature based method are needed, which will be done in future.

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