AUTOMATIC DETECTION OF NEW BUILDING CONSTRUCTION FROM SENTINEL-1 MULTI-TEMPORAL IMAGERY

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Abstract

An automatic processing chain for detecting a new building construction solely from multi-temporal satellite synthetic aperture radar data was developed and introduced in the paper. Although it was developed while utilising Sentinel-1 imagery, it can be adapted to other satellite radar systems. The solution was developed to be used mainly in protected critical infrastructure zones to identify prohibited constructions. In order to eliminate detection of changes happening on natural surfaces due to common agricultural works or seasonal changes in vegetation, the algorithm mainly uses a combination of a backscatter change statistical evaluation and coherence change evaluation. The solution was first tested in a selected area, including urban and natural environments. Although mean success in detecting a new building construction from a single track was only 36%, processing data from more tracks significantly increased the probability of a new building detection, especially of the larger ones.

Keywords: synthetic aperture radar; building construction; detection; Sentinel-1

1. INTRODUCTION

Protection zones prohibiting any construction activity are commonly defined around critical infrastructure elements. Due to the extensive area of some protection zones and the extension of the area in which these protection zones are distributed, it is impossible to arrange their regular visual inspection by the critical infrastructure operator staff. Therefore, ways are being sought to ensure that these areas are monitored at a minimum cost. One of the possibilities is using satellite remote sensing.

Various intensity (amplitude) change detection algorithms based on synthetic aperture radar (SAR) data aimed at buildings and urbanisation detection were developed. Several studies (Dong et al., 1997, Bruzzone et al., 2004, Hu and Ban, 2008, Kimura, 2008, Koppel et al., 2015, Koppel et al., 2017, Zhang et al., 2020) detected new suburbs built in the cities or clusters of changed urban areas and dealt with the recommendations for data and their pre-processing. On the other hand, only a few authors worked on detecting a single new building after its construction from satellite SAR. Marin et al. (2015) used high-resolution X-band data to identify changes (new construction or demolition) in the level of individual buildings in an urban environment. They applied fuzzy rules to increase the reliability of detecting buildings observed within several to many pixels. They were aware that the representation of construction in SAR imagery depends on factors as radar signal incidence angle, size and orientation of a building and complexity of the surrounding environment. Li et al. (2019) investigated pre-processing options to detect new buildings (observed in several to many pixels) after finishing their construction from differences between two Sentinel-1 images collected over a period of more than ten months in the urban environment.

This study introduces a developed automatic algorithm for detecting new building construction based on reflectance intensity changes within the time series of Sentinel-1 imagery. Besides a description of the algorithm itself, results from the first performance tests are presented.

2. MATERIALS AND METHODS

2.1. New building construction detection processing chain methodology

The developed solution for a new building construction detection is supposed to be used primarily in protected zones of critical infrastructure, therefore in areas where mainly natural surfaces can be expected. In order to eliminate detection of changes happening on natural surfaces (mainly agricultural works on fields), the algorithm uses a combination of a backscatter change, coherence change and an absolute value of the backscatter and spatial coherence in the post-event stack of images.

As an input, SAR images in SLC format are used, radiometrically calibrated to backscattering coefficient $\gamma 0$ [dB] and geocoded. The ground resolution is set to 10 m in azimuth and range directions in our approach. Spatial filtering is performed using the improved Sigma-Lee filter (Lee et al., 2009) with the smallest possible window (3x3 pixels). Coherence maps are calculated for subsequent images, preferably over a constant time interval, and are attributed to the later acquisition date of the two images.

Data stacks are formed for a given (event) date: a pre-event stack and a post-event stack (each of them with 5-10 subsequent images, i.e. 1-2 months). Mean, and standard deviation of backscatter value are calculated for each point and each stack, and it is statistically evaluated if the backscatter difference is significant enough to be classified as a change. Also, the mean and standard deviation of the coherence are calculated, and the change in coherence is evaluated.

A fuzzy approach with two thresholds (these may change according to the SAR incidence angle) allows to quantify the change and the absolute values themselves and combine the change metrics: it is required that both backscatter values and coherence increase to a different value.

The large size of both stacks allows to improve the sensitivity of the technique (which is crucial, with the Sentinel-1 resolution), but only a 1-2 months old change can be detected. In order to further eliminate numerous false detections, a longer timeline is processed, and only spots with detected changes for subsequent 2-3 dates are considered a real change.

2.2. Evaluation methodology

The following approach was applied:

1. Data from ascending and descending Sentinel-1 tracks were processed over a long-term period.

2. Each detected change was classified using three categories to determine the type of surface on which it happened (building; artificial surface; natural surface).

3. Each detected change was confirmed or not confirmed to happen via evaluation of available reference data sets. Publicly available satellite, aerial and ground imagery of various types was used for this purpose.

4. Assessment of building detection was performed to determine the success rate of building detection.

Evaluated new buildings were sorted in two categories based on their size: a) family house; b) larger building. If a sum of maximum building length and width exceeded 45 m, it was classified as category b).

2.3. Selected test area for evaluation of the developed solution

An area of 21 km^2 in the western part of the Ostrava city in the Czech Republic was selected for the first evaluation of the developed solution performance. Except for built-up areas of various character and functions, it also contains natural surfaces as agricultural fields, forests, parks, etc. The processed time period spanned from the beginning of 2017 till June 2020. Using knowledge about building construction activities in the area and an analysis of remote sensing data, 36 new buildings were identified to be built within the given period. 24 buildings had a single-family house size; 12 buildings were larger.

RESULTS

Data from the above-described testing area were processed from two ascending (A) and two descending (D) tracks. Table 1 presents a summary of identified changes over all tracks. On average, 62% of changes were detected on buildings and 33% on artificial surfaces. Besides a new building construction, reconstructions of existing buildings were often detected, and they typically included an exchange of roof material and/or thermal insulation of the building shield. Among artificial surfaces, changes were mostly detected in industrial and shopping zones, on parking lots, roads and around family houses. Out of the total 188 evaluated changes, 86.7% were confirmed; the rest represent either a false positive detection or a real change that could not be verified using reference data. At least some of the unconfirmed changes are expected to represent real changes.

Rates of new building construction detection success from individual tracks are provided in Table 2. Depending on the track, 22% to 43% of all new buildings were detected from a single track, with much higher success rates (up to 61%) for large buildings and logically lower success rates (down to 21%) for buildings of a size of a family house. Diverse results reached by individual tracks can be attributed to the visibility of each construction site from the particular viewing angle (both horizontal and vertical), i.e. orientation, size and possible shadows from the surroundings. In addition, the processing parameter settings were different for each swath, as the spatial coherence and backscatter values were significantly different for different incidence angles.

Table 1. Summary of changes detected in all four processed tracks.

Type of change	Confirmed changes	Not confirmed changes	Total (Percentage)
Building construction	48	14	117 (62.2%)
Building reconstruction	55		
Other on artificial surface	58	3	61 (32.5%)
Other on natural surface	2	8	10 (5.3%)
Total (Percentage)	163 (86.7%)	25 (13.3%)	188

Table 2. Success rates of new building construction detection in individual tracks. The northern part of the testing area was not processed in the track D124_IW2.

Track_swath	Processed period	Number of buildings for detection	% of detected all buildings	% of detected small buildings	% of detected large buildings
D51_IW3	2017/01 - 2020/06	37	43.2	33.3	61.5
D124_IW2	2017/02 - 2020/06	26	42.3	30.8	53.8
A73_IW3	2017/01 - 2020/06	37	35.1	25.0	53.8
A175_IW2	2017/02 - 2020/06	37	21.6	8.3	46.1

CONCLUSIONS

We introduced a developed solution for automatically detecting a new building construction from Sentinel-1 imagery. It was tested in a selected area containing urban and natural environments. In total, 188 changes were detected during the processed period and checked against reference data sets. As 95% of all changes were detected on buildings or on other artificial surfaces, the developed solution was able to successfully suppress potential false positive detections related to common agricultural works at fields that are often connected to significant changes of backscatter intensity in radar imagery.

Mean success in detecting a new building construction from a single track processing was

36%. Processing data from more tracks significantly increased the probability of a new building detection as 85% of larger buildings were detected at least from one processed track. Since larger buildings were detected with significantly higher success rates than smaller ones, the spatial resolution of Sentinel-1 imagery seems to be a substantial performance limitation of the developed solution.

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