URBAN MONITORING AND CHANGE DETECTION OF CENTRAL TOKYO USING HIGH-RESOLUTION X-BAND SAR IMAGES

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ABSTRACT

Urban areas grow and change rapidly all over the world. Hence, regular and up-to-date information on urban changes is required for urban planning and disaster management. In this study, two temporal TerraSAR-X images are used to monitor urban changes. The study area is focused on a part of central Tokyo, Japan. Firstly, the changes between two images are checked by color composition. Then the difference and the correlation coefficient between the two images are calculated with a sliding window. A new factor that combines the difference and the correlation coefficient is proposed to detect changed areas. Finally, two high resolution optical images are introduced to verify the accuracy of the detection results.

Index Terms— TerraSAR-X image, difference, correlation coefficient, change detection, high resolution optical image

1. INTRODUCTION

Monitoring urban growth and change is an important issue for urban planning and disaster management. Current approaches to urban monitoring generally involve ground surveys and interpretation of aerial photographs. The improvement of remote sensing technology makes satellite image become an efficient method to collect urban information. Compared to optical sensors, synthetic aperture radar (SAR) does not suffer from the limitations of weather condition. The high resolution of images (ALOS/PALSAR and TerraSAR-X) is well suited for urban applications, e.g. urban modeling as well as for damage mapping after disasters.

Urban areas are generally characterized by high SAR backscatter intensity due to the predominance of single- and double-bounce backscattering [1]. Previous studies using multi-temporal SAR data for change detection have achieved some promising results. Rignot et al. [2] used the backscattering intensity ratio and the coherence value from repeat pass ERS-1 SAR data to identify scene changes. Grey et al. [3] used a multi-temporal sequence of ERS interferometric coherence data acquired between 1993 and 1999 for automated mapping of urban changes in South Wales, UK. Liao et al. [4] detected land-cover changes in urban areas based on backscattering intensity and long-term coherence from ERS-1/2 InSAR data. These studies focused on using ERS interferometric coherence data to detect the land cover changes in urban areas. However, TerraSAR-X images have higher resolution (1.25 m) to detect more details, e.g. a single building change. Matsuoka and Yamazaki [5] developed an automated method to detect hard-hit areas in the 1995 Kobe Earthquake, using the backscattering coefficient difference and correlation between pre- and post-event ERS images. This method can also be used to detect urban changes in TerraSAR-X images.

In this paper, two temporal TerraSAR-X images of central Tokyo are used to detect urban changes by an improvement method proposed in Ref. [5]. The result of change detection is compared with two high resolution optical images to verify the accuracy.

2. STUDY DATA AND IMAGE PREPROCESSING

The study area focuses on central Tokyo, Japan since there are many new constructions every year in this area, as shown in Fig. 1. Two TerraSAR-X images taken in different years by HH polarization from the descending path, shown in Fig. 2 (a, b), were used to detect urban changes. The first image was taken on May 23th, 2008 with 42.82° incidence angle, and the second one on November 23th, 2009 with 42.81° incidence angle at the center. After the enhanced ellipsoid correction (EEC), two images were transformed into 1.25 m/pixel.

Two high resolution optical images shown in Fig. 3 (a, b) were introduced as truth data. The first image was taken on March 20th, 2007 by QuickBird (QB), one year before the first TerraSAR-X image. The second image was taken on May 11th, 2010 by WorldView-2 (WV2), a half year after the second TerraSAR-X image. The WV2 image includes 8 multi-spectral bands from costal blue to NIR2, but only 4 basic bands (B, G, R, NIR) were used in this study. By pansharpening procedure, a 0.6 m resolution QB image and a 0.5 m resolution WV-2 image were obtained.

Since the images were taken from 3 different kinds of sensor, several image pre-processing steps were applied before change detection. The first step is co-registration. The two TerraSAR-X images have been geo-coded after EEC,

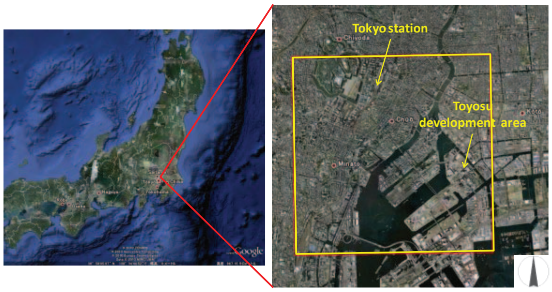
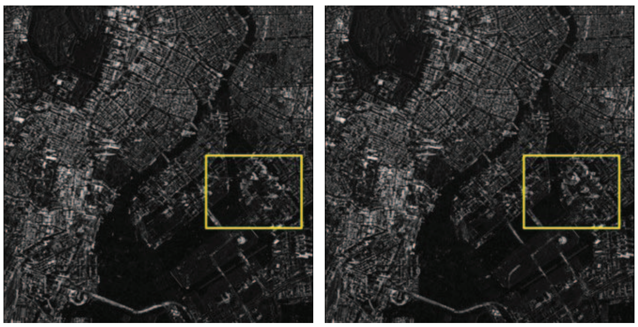


Fig. 1 The study area in central Tokyo, Japan including a new developing area, Toyosu.



(a) (b)

Fig. 2 TerraSAR-X images taken on May 23th, 2008 (a) and on Nov. 23th, 2009 (b).

(a) (b)

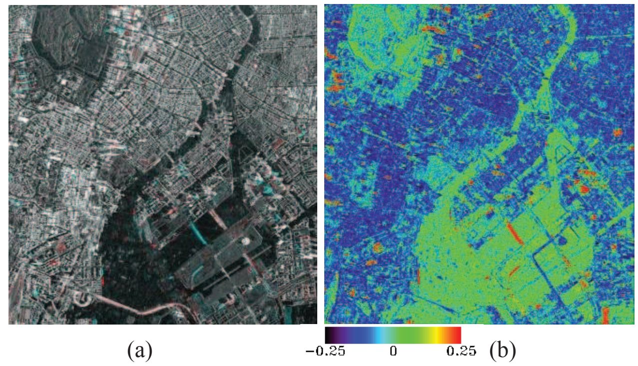
Fig. 3 False color composite images of QuickBird taken on March 20th, 2008 (a), and WorldView-2 taken on May 11th, 2010 (b).

and hence they were matched perfectly. Eight points chosen manually from each image were used to match the optical images to the TerraSAR-X images. The resolutions of the optical images, which were higher than the TerraSAR-X images, were deteriorated to 1.25 m after co-registration. Then digital numbers of the two TerraSAR-X images were transformed to Sigma Naught (σ^0), which represents the radar reflectivity per unit area in the ground range by Eq. (1).

$$\sigma^0 = 10 \cdot \log_{10}(k_s \cdot |DN|^2) + 10 \cdot \log(\sin\theta_{loc}) \qquad (1)$$

where k_s is the calibration factor which can be found in the header file, and θ_{loc} is the local incidence angle which is derived from the Geocoded Incidence Angle file.

Lastly, Lee filter [6] was applied to remove the speckle noises from the SAR images. Considering the building size and the image resolution, the window size of Lee filter was set as 9×9 pixels (about 11 m×11 m), similar to a small building's size.



(a) (b)

Fig. 4 Color composition of the two temporal TerraSAR-X images (a), and a rainbow color image of the factor z (b).

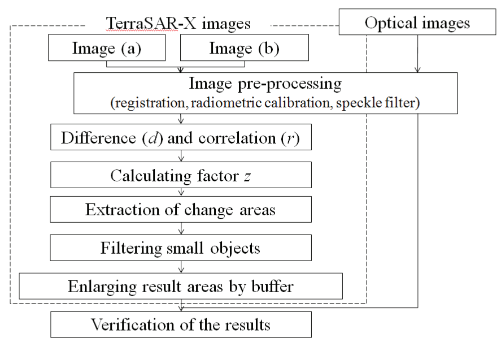


Fig. 5 Flowchart of change detection from the two temporal TerraSAR-X images

3. CHANGE DETECTION FROM TERRASAR-X IMAGES

Firstly, color composition of the TerraSAR-X images was applied to see changed areas visually, as shown in Fig. 4 (a). The first image taken in 2008 was plotted in Red, and the second image taken in 2009 was plotted in Blue and Green. From Fig. 4 (a), the red area represents the reduction of backscatter, which can be considered as removed buildings; the cyan area represents the increase of backscatter, which can be considered as new constructions. Many urban changes can be seen in Toyosu, a new re-development area near the Tokyo Station. A new bridge can also be seen clearly in cyan from the color composite image.

To detect these changes automatically, the difference of the backscattering coefficients and the correlation coefficient were derived from the two images. This method was employed in Ref. [5] to detect changes due to natural disasters in urban areas. In our case, an improved method was applied to urban changes in a normal time. The flowchart of the change detection method is shown in Fig. 5. Firstly, the difference (d) is calculated by Eq. (2) and the correlation coefficient (r) is calculated by Eq. (3).

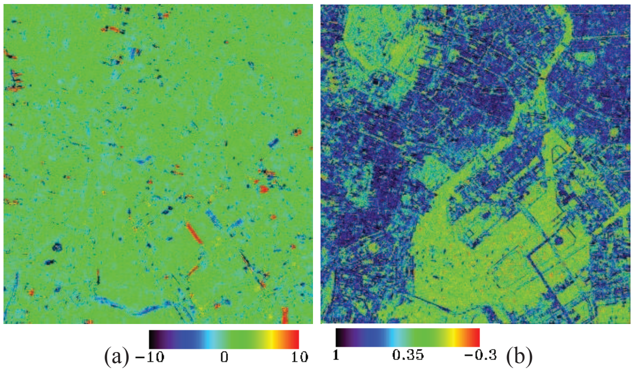


Fig. 6 The resulted images of the difference (a), and the correlation coefficient (b).

$$d = \bar{I}a_i - \bar{I}b_i \tag{2}$$

$$r = \frac{N\sum_{i=1}^{N} Ia_i Ib_i - \sum_{i=1}^{N} Ia_i \sum_{i=1}^{N} Ib_i}{\sqrt{\left(N\sum_{i=1}^{N} Ia_i^{\,2} - \left(\sum_{i=1}^{N} Ia_i\right)^2\right)\cdot\left(N\sum_{i=1}^{N} Ib_i^{\,2} - \left(\sum_{i=1}^{N} Ib_i\right)^2\right)}} \tag{3}$$

where i is the pixel number, Ia_i and Ib_i are the backscattering coefficient of the post- and pre-event images, $\bar{I}a_i$ and $\bar{I}b_i$ are the corresponding averaged values over the N (=$k \times k$) pixels window surrounding the i-th pixel.

In this study, the window size is set as 9×9 pixels, the same as the speckle filter's. The resulted images are shown in Fig. 6 (a-b). In the difference image, urban changes can be shown by either negative or positive values. In the correlation image, a low correlation value means a change. However, even there was no change, vegetation and water areas are shown to be in a very low correlation value since their backscatter would change so much depending on the wind condition.

The changed areas can be detected from the difference and correlation coefficient images by respective threshold values. However, the results of the detection from the difference and the correlation coefficient were not completely matched at the some locations. Then a new factor (z) calculated by Eq. (4), which combines the difference and the correlation coefficient, was proposed to represent changes uniquely.

$$z = \frac{|d|}{Max(|d|)} - c \cdot r \tag{4}$$

where Max(|d|) is the maximum absolute value in difference and c is the weight between the difference and the correlation coefficient.

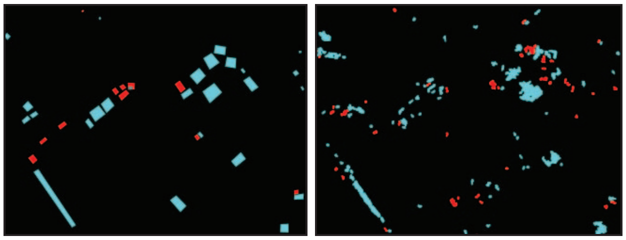
Since the correlation coefficient was very sensitive to subtle changes, it shows a low value even there was no big change. Hence, in this study the weight for difference was set as 4 times of that for correlation. The resultant factor z falls in the range from -0.25 to 1.25, and it is shown in Fig. 4 (b). A high value means high possibility of change. Comparing with the color composition shown in Fig. 4 (a), the colored areas in (a) showing change can be seen by red color (high value) in (b). From the histogram of the z value, the mean value (μ) is -0.04 while the standard variation (σ) is 0.12. The threshold value was calculated as the mean value pulsing twice of the standard deviation, to detect changed areas. In this case, the areas with the z value larger than 0.20 were extracted as changed areas.

Fig. 7 The extracted change areas overlapping on the QuickBird image taken in 2007.

Then the extracted areas were overlapped on the difference image, to divide it into positive and negative changes. Since the X-band presents strong backscatter for metal, several vehicles also show strong backscatter as well as buildings. To reduce these noises, the detected areas with the size smaller than 8×8 pixel (10×10 m) were removed from the result. The difference and correlation coefficient were calculated in a slide window, and hence, the detected areas were smaller than the original. The buffer zone surrounding the detected area with 5 pixels (half of the slide window size) was extracted as change areas. The final result of change detection is shown in Fig. 7, overlapping on the QB image. There were 2.8% of the whole TerraSAR-X image that were changed between 2008 and 2009, including 1.6% newly built and 1.2% removed construction. Converting to the area unit, about total 6.1 km^2 areas have new constructions while removed constructions correspond to 4.6 km^2. Since the backscatter of SAR is from both building walls and roofs, mainly from walls in case of high-rise buildings, the areas of change from the SAR images were not exactly the areas of change in the ground level.

4. VERIFICATION

A QB image taken in Match, 2007 and a WV-2 image taken in May, 2010 were introduced to verify the accuracy



(a) ■ Postive change ■ Negative change (b)

Fig. 8 Manual detection results of the changed building' footprints (a), and automated results of the changed areas (b).

of the change detection. The comparison was focused on a part of the area in Toyosu. The changed areas were detected visually by comparing buildings in the two optical images one by one. Since the off-nadir angle of QB is 10 degrees while WV-2 is 21 degrees, a building in the two images is seen with different heights and also to lean to different directions. It was difficult to detect the shapes of the changed buildings. Then the footprints of the changed buildings were detected manually, as shown in Fig. 8 (a). Comparing with the automated result shown in Fig. 8 (b), the extracted areas were mostly matched with the changes detected from the optical images. In the automatically detected result, several areas extracted as remove constructions were occurred due to the shadow of a new building nearby. In the future, this kind of errors would be removed by considering a new building and surrounding removed buildings as one set when they are lined in the direction of radar scattering.

Since the TerraSAR-X images were taken by side-looking, buildings show displacements in the images. Most of the automated results were the backscatter from building's walls. Hence, the detected areas were away from the footprints. The accuracy cannot be detected by simply overlapping the two results. In this case, a manual comparison was applied. Firstly, the image of footprints and the automated results were overlapped on the color composition of the two temporal TerraSAR-X images. If the shape of the footprints and the detected areas belong to the same building, then they were seen as the matched results. The result of comparison was shown in Table I.

Most of new built buildings were detected successfully. The low accuracy of removed buildings was caused by radar shadow. Four of omission error buildings were in the shadow of neighbor buildings, and hence, the changes cannot be detected after they were removed. Another omission error was a low building with a flat proof. The backscatter in the first SAR image was too small to be caught in the change detection. There were still many commission (false positive) errors in the results from the TerraSAR-X images, even after removing small objects. To improve the accuracy, the threshold value in the change detection will be discussed in a future study.

Table I. Accuracy of change detection from the TerraSAR-X images

	Remove		New built	
	Numbers of objects	pixels	Numbers of objects	pixels
Results from TerraSAR-X images	39	27,085	69	95,943
Matched changes (1)	20	17,462	40	80,041
Commission errors	19	9,623	29	15,902
Accuracy (matched (1)/results)	51.3%	64.5%	58.0%	83.4%
Visual results from optical images	11	15,628	26	88,600
Matched changes (2)	6	9,415	24	80,305
Omission errors	5	6,213	2	8,295
Accuracy (matched (2)/visual results)	54.5%	60.2%	92.3%	90.6%

5. CONCLUSIONS

In this study, urban changes in central Tokyo were detected from two temporal TerraSAR-X intensity images, employing a new factor combining the difference and the correlation coefficient of the two SAR images. High resolution optical images were introduced to examine the extracted results. 81% of the change buildings could be extracted correctly by the proposed method.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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