USE OF INTERFEROMETRIC SATELLITE SAR FOR EARTHQUAKE DAMAGE DETECTION

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ABSTRACT

Synthetic Aperture Radar (SAR) is one of the most promising remote sensing technologies since it is not affected by clouds and lights. The SAR interferometric analysis, using phase information of backscattering echoes from objects on the earth's surface, is successfully employed to quantify relative ground displacements due to natural disasters. In addition, the complex coherence derived from the interferometric analysis is a suitable and sensitive parameter for the detection of superficial change and the classification of land use. In this paper, we investigated the microwave scattering characteristics of the areas damaged by the 1999 Kocaeli, Turkey earthquake using satellite SAR. From the difference in backscattered intensity and coherence from an interferometric analysis of SAR images taken at different acquisitions, we found that the backscattering property in heavily damaged areas showed significant change, compared with that in minor damage areas. The relationship between building damage and difference of pre- and post-event SAR images was found to relate to the damage level. This trend in the hard-hit areas was due to the fact that the backscattered intensity and the intensity correlation of two images became low. The degree of coherence was found to be a good index to distinguish slight to moderate damage levels.

Introduction

Satellite remote sensing, which can monitor a large area, may provide effective information on determining damage distribution for recovery activities and restoration planning. The present authors have already reported spectral characteristics of the damaged area by comparing satellite optical images with the detailed damage survey results on the 1995 Hyogoken-Nanbu (Kobe) earthquake, and have attempted to identify the damage distribution (Matsuoka and Yamazaki, 1998).

Synthetic aperture radar (SAR) observations can be performed in both day and night time without influence of weather condition. This feature can be useful for effective post-disaster damage assessment, especially when optical remote sensing or a field survey for a large area is difficult. Several researchers reported the interpretation of the building damage distribution using

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SAR amplitude information (Aoki *et al*., 1998; Yonezawa and Takeuchi, 1998) and phase information (Yonezawa and Takeuchi, 1999; Matsuoka and Yamazaki, 2000). Using the phase approach, which has higher sensitivity than the intensity approach, crustal deformation due to seismic events was successfully identified (Rosen *et al*., 1999).

In this paper, the backscattering characteristics for the damaged areas due to the 1999 Kocaeli, Turkey earthquake were investigated using ERS/SAR data and field survey results. Then we attempted an extraction of building damage distribution by a level slice technique using pre- and post-event SAR images.

Microwave Scattering in the Areas of Building Damage

According to our previous studies (Aoki *et al*., 1998; Matsuoka and Yamazaki, 2000), artificial structures show comparatively high reflection due to specular characteristics of structures and ground. Open spaces or damaged buildings have comparatively low reflectance because microwaves are scattered to different directions. A schematic diagram of a surface object and its backscattering property are shown in Fig. 1. Buildings may be reduced to debris by an earthquake, and in some cases, the debris of the buildings may be cleared leaving the ground exposed. Thus, the backscattered intensity determined after a damaging earthquake may become low compared with that obtained before the event. The complex coherence derived from an interferometric analysis is also a suitable and sensitive parameter for detecting superficial changes. Because collapsed buildings exert an influence on phase, the degree of coherence becomes small between pre- and post-event images.

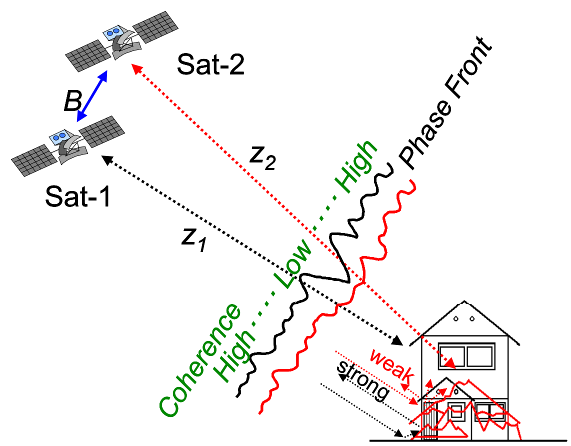

Figure 1. Schematic diagram for detecting building damage using repeat-pass radar observations.

The 1999 Kocaeli, Turkey Earthquake

Ground Truth Data

On August 17, 1999, a magnitude (Mw) 7.4 earthquake struck the northwestern region of Turkey as shown in Fig. 2 and caused immense destruction to man-made structures with over confirmed 14,000 deaths. The total numbers of collapsed and moderately damaged buildings are approximately 66,000 and 67,000, respectively. Approximately 67,000 house units are classified as slightly damaged. A

Figure 2. Northwestern region of Turkey.

detailed and systematic field survey on building damage was conducted by a Japanese team in Golcuk and Degirmenderem (AIJ Reconnaissance Team, 1999). Using the survey data, the damage ratios of buildings in the city-block level were calculated.

The collapse ratios of the buildings were evaluated for each block in Golcuk, defined as the ratio of the number of buildings classified as collapse and the total number of buildings in each block. The damage rank was classified into the five categories as rank A, B, C, D, and E, which correspond to the collapse ratios of 0-6.25, 6.25-12.5, 12.5-25, 25-50, and 50-100%, respectively.

ERS/SAR Images and Processing

Series of radar observations including tandem flights using ERS-1 and ERS-2 was conducted over the affected area before and after the earthquake. The image pair, which consists of August 13 and September 17, 1999 (pair 8/13-9/17), with 34-day difference and 80m baseline distance, and the pair of August 12 and August 13, 1999 (pair 8/12-8/13), with 1-day difference and 240m baseline distance, were used to investigate the variation of backscattering property in the damaged areas. All the images were registered to the 99/08/13 data by the nearest neighbor method, using tie points derived from the optimum pixel pair determination, by searching pixel by pixel, at the position that yields the highest correlation between two single-look amplitude images.

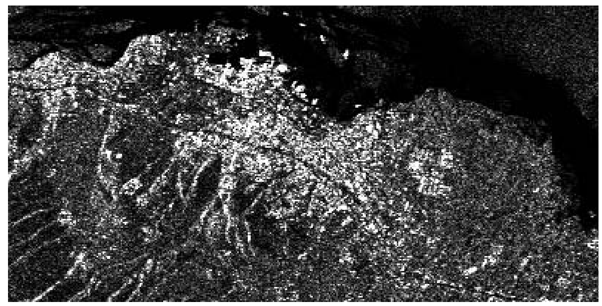

Figure 3. ERS/SAR amplitude image of Gulcuk. (September 17, 1999)

Figure 3 shows a pseudo multi-look amplitude image created by averaging 5 azimuths and one range pixels to single-look one, which observed Golcuk on September 17, 1999. The amplitude difference value was calculated for each pair, and then the intensity difference images were generated. The correlation coefficient between two single-look amplitude images was calculated within a small corresponding window, with pixel sizes of 15 for the azimuth and 3 for the range direction. Following this procedure, we created the correlation images that have the same size as described using a spatial averaging. The degree of coherence, which indicates the correlation between two co-registered complex SAR images by calculating the phase of the backscattering echo, was also used as an index to indicate the changes in the affected area. The window sizes for the coherence calculation and the averaging were same as those for the intensity correlation calculation.

Backscattering Characteristics of Damaged Areas

The pixels that correspond to the area of each damage rank were selected from the SAR images in order to examine the characteristics of the intensity difference, the intensity correlation, and the degree of complex coherence in the damaged areas. The numbers of selected pixels were approximately 1,800, 840, 720, 1,000, and 80 for the damage ranks A, B, C, D, and E, respectively.

The characteristics of the mean value and the standard deviation of the intensity

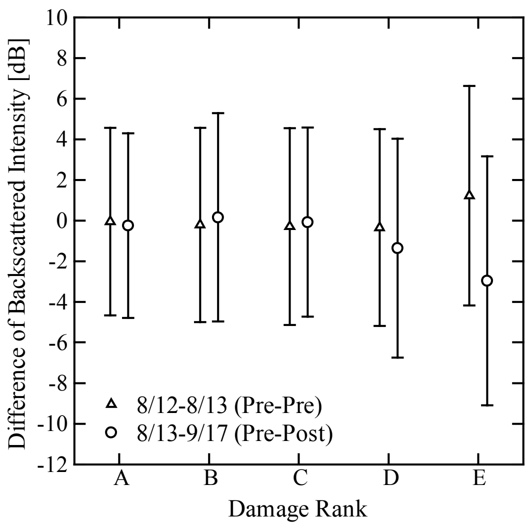

Figure 4. Difference in backscattered intensities from two time instants for different damage rank.

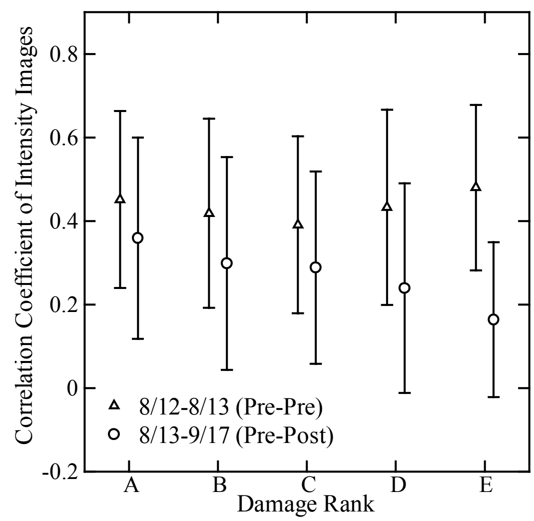

Figure 5. Correlation coefficient of intensity images between two time instants for different damage rank.

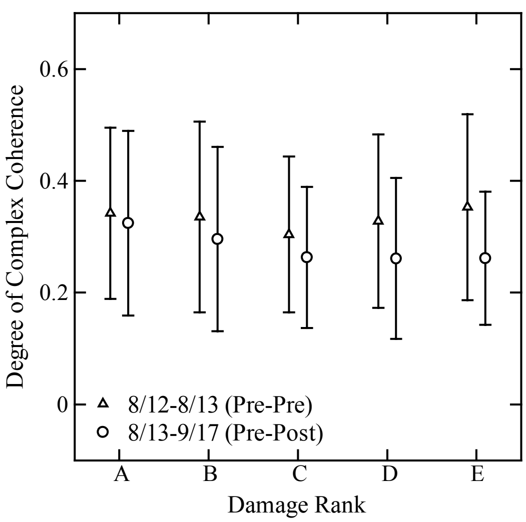

Figure 6. Degree of complex coherence between two time instants for different damage rank.

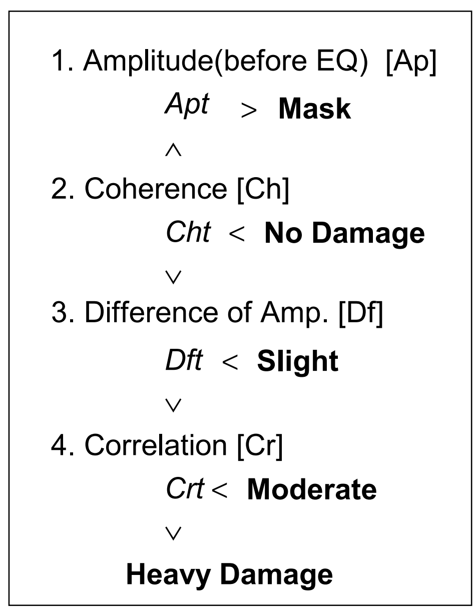

Figure 7. Procedure for damage estimation.

difference in each damage rank for the two pairs are shown in Fig. 4. Although there is a scatter in the intensity difference for each damage rank, the mean value in each rank decreases as the damage rank increases, for the pair 8/13-9/17. This trend is remarkable in the severe damage ratios (D and E). In the pre-event images' pair of 8/12-8/13, this trend cannot be observed because they are not affected by the destruction due to the earthquake.

The same behavior in case of the intensity correlation and the complex coherence are shown in Figs. 5 and 6, respectively. As the damage level increases the intensity correlation

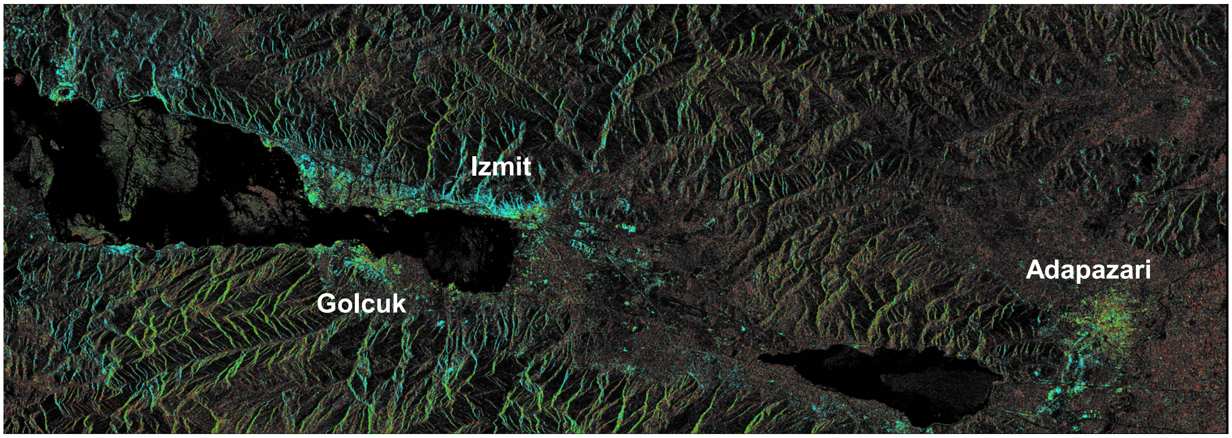

Figure 8. Estimated damage distribution overlaid on SAR amplitude image.
(Heavy: red, Moderate: yellow, Slight: green, No damage: blue)

decreases gradually for the pair 8/13-9/17, which agrees with the results of the Kobe study (Matsuoka and Yamazaki, 2000). As shown in Fig. 6, the degrees of coherence in the slight damage area (A) are relatively high in comparison with those in the moderate (B, C) or heavy damaged areas (D, E) for the pair 8/13-9/17 although the standard deviations are quite large. For the pre-event pair 8/12-8/13, the correlation of backscattered intensity and the damage level are seen to have no relationship. A similar tendency for the two pairs is observed in the complex coherence shown in Fig. 6.

Estimation of Damage Distribution

According to the results obtained above, it is found that the intensity difference can identify large surface changes, and that the intensity correlation is sensitive to a wide range of earth surface changes while the degree of coherence is sensitive to only slight surface changes. A simple procedure shown in Fig. 7, can be proposed to extract the damage areas based on a level slice method. We determined and assigned threshold values, *Cht* (value is 0.35), *Dft* (-2.0), and *Crt* (0.2) in the coherence, the amplitude difference, and the correlation images, respectively. First, the pixels whose coherence values are smaller than the *Cht* are assigned as nondamaged. The pixels whose coherence vales are greater than or equal to *Cht* are moved to the next step of the discriminate procedure. Then, slightly damaged areas are extracted using the *Dft* in the difference image. The pixels whose correlation vales are smaller than *Crt* are assigned to heavily damaged. The rest of pixels are assumed to be moderately damaged. The result of the estimation is shown in Fig. 8. In Golcuk area, the estimated damage distribution from SAR images almost corresponds to the result of the field survey. The heavily damaged and nondamaged areas spread widely in Adapazari and Izmit areas, respectively. These results are relatively good agreement with the several damage survey reports (e.g., AIJ Reconnaissance Team, 1999; MCEER, 2000). However, since these results were derived from the pairs with short baseline distances and using C-band microwaves, a further study based on SAR images with different acquisitions and satellites should be necessary to reach a general conclusion on grasping damage distribution from the space.

Conclusions

This paper demonstrated a quantitative evaluation on the backscattering properties of SAR images, such as the difference of intensities, intensity correlation, and complex coherence between different acquisitions for the areas hit by the 1999 Kocaeli, Turkey earthquake. ERS/SAR images taken before and after the event and detailed field survey data were employed to examine the possibility of capturing the damage distribution. The building damage ratio for city blocks obtained by the field survey and the backscattering properties derived from the SAR images were compared.

In the areas of heavy building damage, the backscattered intensity and the intensity correlation between pre- and post-event images were found to become low. The degree of complex coherence was found to be useful to classify small damage levels. The estimated damage distribution from SAR images almost corresponded to the results by a field survey. In spite of these results regarding the mean characteristics of SAR images, a large degree of randomness exists in the backscattering properties for each damage classification. A further study is suggested till a general statement for the earthquake damage survey in urban areas using satellite SAR is made.

Acknowledgments

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