Application of the Damage Detection Method Using SAR Intensity Images to Recent Earthquakes

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***Abstract*-One of the remarkable characteristics of synthetic aperture radar (SAR) is to record physical value called the backscattering coefficient of the earth's surface not depending on weather conditions and sun illumination. Therefore, SAR could be a powerful tool and be used to develop a universal method for grasping damaged areas by disasters such as earthquakes, forest fires and floods. Detailed ground truth data for building damage due to the 1995 Kobe earthquake provided us the opportunity to investigate the relationship between the backscattering property from SAR images and the degree of damage. From the above analysis we have already developed a method to detect areas of building damage. In this paper, we applied this method to the images taken over the area hit by the 1999 Kocaeli, Turkey and the 2001 Gujarat, India earthquakes, and then the accuracy of the proposed method was examined by comparing the results of the analyses with those from the damage surveys.**

I. Introduction

SAR interferometric analyses using the phase information successfully provided the quantitation of the relative ground displacement level due to natural disasters [1], as well as the inventory of built environment [2]. The complex coherence obtained from the interferometric analysis enables us to evaluate building areas with slight damage due to earthquakes [3]. But it is a parameter sensitive to the satellite geometry, acquisition duration and wavelength of radar [4]. The backscattering coefficient of the earth's surface, having amplitude information (intensity), is less dependent on the above-mentioned conditions [5]. Hence, the backscattering coefficient derived from SAR intensity images may be used for developing a universal method to identify damaged areas in disasters such as earthquakes, forest fires and floods. Detailed ground truth data with building damage due to the 1995 Kobe earthquake provided us the opportunity to investigate the relationship between the backscattering property and the degree of damage. From this analysis, we have already developed a method to detect areas of building damage. In this paper, we briefly introduce the automated damage detection method and apply this method to the images taken over the areas hit by the 1999 Kocaeli, Turkey and the 2001 Gujarat, India earthquakes, and then the validity of the technique is shown from the comparison with the damage survey data.

II. The Method of Automated Damage Detection

The backscattered strength of microwave reflects the roughness of the surface, the moisture level of the area, and the incident angle of the microwave and its wavelength. Generally, man-made structures show comparatively high reflection due to specular characteristics called the "cardinal effect of structures and ground." Open spaces or damaged buildings have comparatively low reflectance because microwaves are scattered in different directions. Based on the above characteristics, we have already developed an automated method to detect the areas with severely damaged buildings using the time-series SAR datasets for the Kobe earthquake [6]. This empirical method is described in the next paragraph.

We prepare two muti-looked intensity images taken before and after an earthquake. It is desirable that the acquisition dates are close, as much as possible, to the earthquake occurrence day and both observation conditions are similar. However, the method was successful in the damage detection for the Kobe example, even in the case that the image pair (ERS: 1994/10/12, 1995/05/23) having quite different observation orbits before and after the earthquake. After co-registration for pre- and post-event images, each image is filtered using Lee filter [7] with 21 x 21 pixel window. The difference in the backscattering coefficient d in (1) and the correlation coefficient r in (2) are derived from the two filtered images. Then, we calculate the discriminant score z obtained by (3). The pixel whose value z is high is assigned as a severely damage area.

$$d = 10 \cdot \log_{10} \hat{I}a_i - 10 \cdot \log_{10} \hat{I}b_i \tag{1}$$

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

$$z = -2.140\, d - 12.465\, r + 4.183 \tag{3}$$

where i is the sample number, Ia_i and Ib_i are the digital numbers of the post- and pre-images, $\hat{I}a_i$ and $\hat{I}b_i$ are the corresponding averaged digital numbers over the surroundings of pixel i within a 13 x 13 pixel window, and the total number of pixels N within this window is 169 to compute the two indices [6]. Focusing on urbanized areas to detect building damage, the pixels whose backscattering coefficient was smaller than the assigned threshold value is masked in the vale z distribution.

III. SAR Dataset of Recent Earthquakes

Satellite SAR observed the stricken areas by the recent earthquakes as well as the Kobe event. We selected two destructive earthquakes, the 1999 Kocaeli, Turkey and the 2001 Gujarat, India, which generated a large number of collapsed

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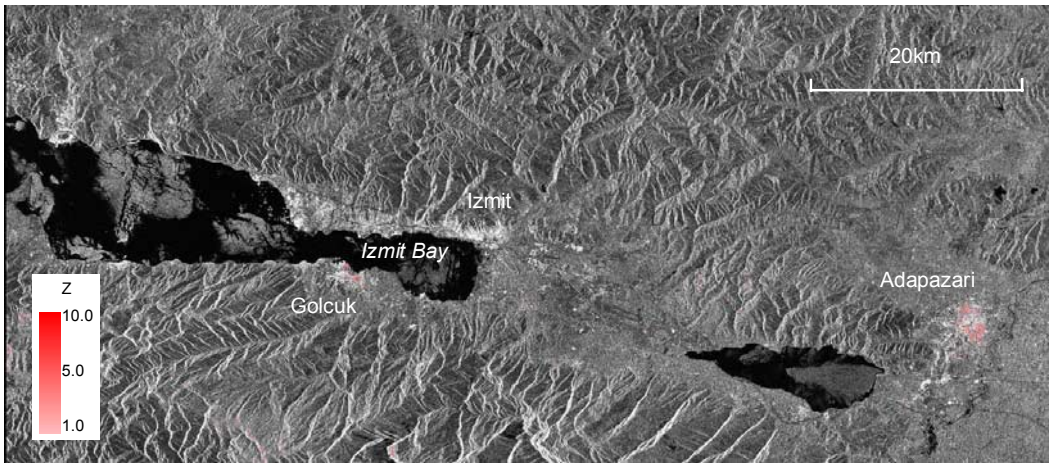

Fig. 1. Distribution of the value z overlaid on the intensity image taken over the affected area by the 1999 Kocaeli, Turkey earthquake.

buildings and human causalities in the large areas, for demonstrating the validity of the method.

On August 17, 1999, a moment magnitude (Mw) 7.4 earthquake shook the northwestern region (Kocaeli) of Turkey. Series of radar observations of ERS-1 and ERS-2 were conducted over the affected area before and after the event. The image taken on August 13 and September 17, 1999 were used for the pre- and post-earthquake images, respectively. Because the perpendicular separation of the two satellites called the baseline *Bp* is approximately 30m, this pair is also perfectly suitable for an interferometric study. One and half years later, the Gurarat earthquake (Mw7.5) devastated the western part of India on January 26, 2001. Canadian satellite RADARSAT with the fine-beam mode whose ground (pixel) resolution and incident angle are 8m and 46 degrees, respectively, flew over around Bhuj city on February 11, 2001. We used the image taken on December 31, 1999 for the data before the Gujarat earthquake. Using this pair, the damage detection by the coherence of phase information cannot be expected since the time interval and *Bp* of the two acquisitions are more than 400days and 6km, respectively.

IV. Comparison Between the Estimated and Actual Damage Distributions

Using the above-mentioned procedure and the SAR images, the distribution of the discriminant score *z* was formed for each earthquake. The threshold value for masking to select built-up areas is -6dB in the backscattering coefficient. The distribution of *z* value overlaid on the pre-event intensity image was georectified and compared with the GIS-based field survey data.

A. The 1999 Kocaeli, Turkey Earthquake

The distribution of *z* value is shown in Fig. 1. Damaged areas shown in red color are widely detected in Golcuk and Adapazari and not in other cities around Izmit Bay. This distribution is in good agreement with the damage statistics of buildings [8]. In Golcuk, a detailed and systematic field survey on building damage was conducted [9]. The collapse ratio of the buildings was calculated and the mean values and

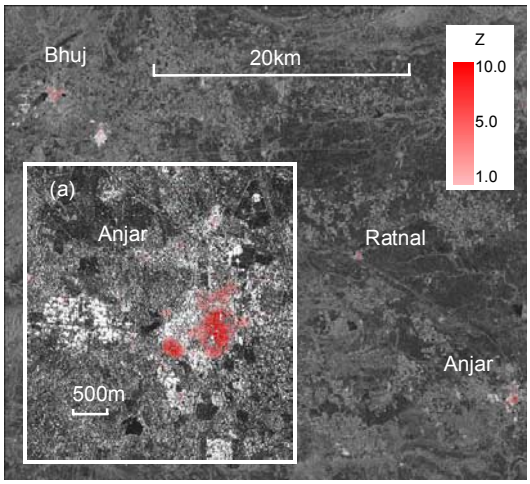

Fig. 2. Distribution of the value z overlaid on the intensity image taken over the affected area by the 2001 Gujarat, India earthquake.

the standard deviations of *z* for the damage levels are shown in Table I. As observed in the Kobe study, the *z* value in this case is also seen to increase as the damage level increases. (see Table I). In Adapazari, comparisons with other field survey data [10][11] were also conducted. A similar tendency between the damage level and *z* value was revealed.

B. The 2001 Gujarat, India Earthquake

The result of applying this method to RADARSAT/Fine images is shown in Fig. 2. The damaged areas, which are locally extracted in some villages between Bhuj and Anjar and both cities, well correspond to those interpreted by aerial photographs [12] and Landsat images [13]. IKONOS had an opportunity to observe the surrounding of Bhuj. The relationship between the estimated damage areas from a post-earthquake IKONOS image [14] and calculated *z* value is also listed in Table I. The *z* value demonstrates the degree of building damage and is relatively close to the result for Golcuk, Turkey. It is considered that the urban district structure and damage pattern of the buildings in India are similar

TABLE I
THE MEAN AND STANDARD DEVIATION OF DIFFERENCE IN BACKSCATTERING COEFFICIENT, CORRELATION, AND DISCRIMINANT SCORE FOR THE DAMAGE LEVEL

Earthquakes and analized areas	Number of pixels	Mean and standard deviation d [dB]	r	z
The 1995 Kobe, Japan earthquake				
Hanshin district (severe damage ratio [%])				
0 ~ 6.25	2000	-0.29 (0.35)	0.54 (0.14)	-1.96 (2.02)
6.25 ~ 12.5	2000	-0.37 (0.43)	0.50 (0.15)	-1.24 (2.30)
12.5 ~ 25	2000	-0.54 (0.47)	0.48 (0.16)	-0.60 (2.44)
25 ~ 50	2000	-0.71 (0.60)	0.43 (0.17)	0.32 (2.85)
50 ~ 100	2000	-0.95 (0.79)	0.36 (0.18)	1.70 (3.41)
The 1999 Kocaeli, Turkey earthquake				
Golcuk (collapse damage ratio [%])[9]				
0 ~ 6.25	363	-0.36 (0.30)	0.44 (0.14)	-0.55 (1.74)
6.25 ~ 12.5	117	-0.13 (0.30)	0.40 (0.21)	-0.54 (2.66)
12.5 ~ 25	140	-0.49 (0.47)	0.41 (0.16)	0.13 (2.21)
25 ~ 50	218	-0.69 (0.27)	0.36 (0.15)	1.21 (1.85)
50 ~ 100	24	-1.01 (0.07)	0.33 (0.13)	2.18 (1.61)
Adapazari (ratio of heavy damage or collapse [%])[10]				
0 ~ 5	666	0.07 (0.29)	0.46 (0.21)	-1.65 (2.38)
5 ~ 15	589	-0.01 (0.19)	0.46 (0.14)	-1.49 (1.81)
15 ~ 30	2967	-0.04 (0.27)	0.43 (0.14)	-1.07 (1.77)
30 ~ 45	2799	-0.30 (0.29)	0.33 (0.13)	0.74 (1.68)
45 ~ 100	1102	-0.40 (0.28)	0.32 (0.10)	1.07 (1.30)
Adapazari (damage level)[11]				
No to slight damage	13	-0.10 (0.20)	0.46 (0.12)	-1.30 (1.63)
Moderate to Heavy damage	25	-0.16 (0.36)	0.40 (0.10)	-0.43 (1.64)
Catastrophic damage	10	-0.53 (0.20)	0.28 (0.06)	1.81 (1.01)
The 2001 Gujarat, India earthquake				
Bhuj (building damage level)[14]				
Areas without extensive or complete damage	6743	-0.17 (0.91)	0.32 (0.14)	0.58 (2.52)
Extensive damage	1011	-0.80 (0.91)	0.30 (0.11)	2.13 (2.69)
Complete damage	738	-0.92 (0.78)	0.28 (0.11)	2.66 (2.43)

to those of Turkey.

V. CONCLUSIONS

We applied an automated technique for detecting the areas with building damage, which was developed from the experiences of Kobe earthquake using SAR intensity images, to recent destructive earthquakes. The extracted damage distributions were in good agreement with the actual situations investigated by field surveys. In this study, we reconfirmed that the characteristics of this technique has less dependency on the baseline between the pre- and post-event satellites.

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