BUILDING DAMAGE ASSESSMENT OF COMPACT POLARIMETRIC SAR USING STATISTICAL MODEL TEXTURE PARAMETER

Yin Liu, Linlin Li, Qihao Chen, Meng Shu, Zhengjia Zhang, Xiuguo Liu*

Faculty of Information Engineering, China University of Geosciences, Wuhan 430074, P.R. China
Email: chenqihao@cug.edu.cn

ABSTRACT

Accurate building damage assessment is essential to providing decision support for disaster relief and reconstruction. This paper presents a method for building damage assessment using the statistical model texture parameter (SMTP) of compact polarimetric (CP) synthetic aperture radar (SAR). This paper uses the SMTP of CP data to describe the homogeneity of building, and using threshold to extract the collapsed buildings. Then the extent of the damage buildings is evaluated based on the proportion of collapsed buildings in the block. The C band, RADARSAT-2 data is used to present and analyze the performance of the proposed method. Compared with other method, the assessment accuracy is improved. The F1-score (harmonic mean of detection rate and false alarm rate) of serious/moderate/slight damage are 78.37%, 59.30% and 72.48%, respectively, and the overall accuracy is 71.99%.

Index Terms—compact polarimetric SAR, building damage assessment, statistical model texture parameter

1. INTRODUCTION

Accurate building damage assessment is essential to providing decision support for disaster relief and reconstruction. Synthetic Aperture Radar (SAR) is one of the most effective means to obtain disaster information with its advantages such as full-time, all-weather working ability, penetration, etc.

Building damage assessment using only fully polarimetric SAR (PolSAR) data after disaster have been extensively studied. The circular polarization correlation coefficient (ρ), normalized circular polarization correlation coefficient (NCCC), the changes of target decomposition components before and after deorientation were used to extract the collapsed buildings [1-4]. The intact buildings which are not parallel to the SAR flight direction (oriented buildings) were misclassified as collapsed buildings, because they share the similar scattering mechanisms. To this end, Zhao et al.[2] utilized the homogeneous texture to distinguish oriented buildings from collapsed buildings. Shi et al. [5] indicated that the texture features are superior to the polarimetric or the interferometric features in extracting collapsed buildings. Thus it can be seen that texture features is an important feature in building damage assessment.

Compact polarimetric (CP) SAR is a new kind of coherent dual-polarization SAR. Compared with full polarization SAR, CP SAR not only reduces the difficulty of system design and maintenance, but also extends imaging range [6]. In addition, compared with single-polarization, CP SAR keeps polarization information. Now, Indian satellite RISAT-1 and Japanese satellite ALOS-2 have supported for CP SAR mode. In the future, Argentina's satellite SAOCOM-1 and Canadian satellite RCM will also support for CP SAR mode. So these phenomena demand further research on the application of CP SAR in building damage assessment.

This paper presents a method to evaluate the extent of the damage buildings by using the statistical model texture parameter (SMTP) of CP SAR. The performance of this method was validated by the RADARSAT-2 data of post-disaster Yushu earthquake.

2. METHODOLOGY

2.1. Building Damage Assessment Procedures

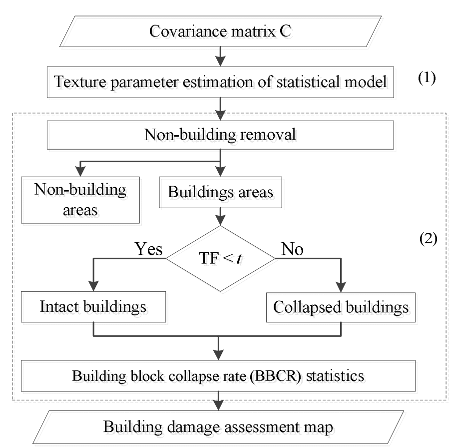

Fig. 1. The flow chart of building damage assessment.

The process of this method includes two main steps. Firstly, the statistical model texture parameter (SMTP) is estimated based on the covariance matrix of CP SAR. Then, the non-building areas are removed with the method of

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literature [7], the collapsed buildings are extracted utilizing the estimated texture parameter, and the build damage assessment map is obtained according to the building block collapse rate (BBCR). The detailed flow chart is shown in Fig. 1

2.2. Compact polarimetry modes

There are three modes for compact polarimetric SAR: π/4、circularly-circularly (CC) and hybrid-polarity (HP) mode. Because the CC mode and the HP mode can be converted to each other, the π/4 and HP mode are commonly used. The π/4 and HP mode CP SAR simulated by full polarimetric data are as follows:

$$\mathbf{C}_{\pi/4} = \frac{1}{2}\begin{bmatrix} C_{11} & C_{13} \\ C_{13}^{*} & C_{33} \end{bmatrix} + \frac{1}{2}\begin{bmatrix} C_{22}/2 & C_{22}/2 \\ C_{22}/2 & C_{22}/2 \end{bmatrix} + \frac{1}{2}\begin{bmatrix} 2\Re(C_{12}/\sqrt{2}) & C_{12}/\sqrt{2} + C_{23}/\sqrt{2} \\ C_{12}^{*}/\sqrt{2} + C_{23}^{*}/\sqrt{2} & 2\Re(C_{23}^{*}/\sqrt{2}) \end{bmatrix} \quad (1)$$

$$\mathbf{C}_{\mathrm{HP}} = \frac{1}{2}\begin{bmatrix} C_{11} & iC_{13} \\ (iC_{13})^{*} & C_{33} \end{bmatrix} + \frac{1}{2}\begin{bmatrix} C_{22}/2 & -i\,C_{22}/2 \\ iC_{22}/2 & C_{22}/2 \end{bmatrix} + \frac{1}{2}\begin{bmatrix} -2\Im(C_{12}/\sqrt{2}) & C_{12}/\sqrt{2} + C_{23}/\sqrt{2} \\ C_{12}^{*}/\sqrt{2} + C_{23}^{*}/\sqrt{2} & 2\Im(C_{23}^{*}/\sqrt{2}) \end{bmatrix} \quad (2)$$

where C_{ij} is the elements of the covariance matrix of PolSAR data, $(\cdot)^{*}$ denotes the conjugate, $\Re$ and $\Im$ are the real and imaginary parts of a complex number, respectively.

2.3 Statistics Model Texture Parameters Estimation

According to product model, the covariance matrix **C** is expressed as the product of texture variable τ and speckle distribution X. Speckle X follows the Wishart distribution. When the texture variable τ is modeled by gamma ($\bar{\gamma}$) distribution with $\mathrm{E}[\tau] = 1$ and the variance is

$$\mathrm{E}[(\tau - \bar{\tau})^2] = \frac{1}{\alpha} \quad (3),$$

the coherency matrix follows the K distribution, and the probability density function (PDF) is expressed as:

$$\mathrm{P}(\mathbf{C}) = \frac{2|\mathbf{C}|^{n-d}(n\alpha)^{\frac{\alpha+nd}{2}}}{\Gamma_d(n)|\mathbf{\Sigma}|^{n}\Gamma(\alpha)}\left(tr(\mathbf{\Sigma}^{-1}\mathbf{C})\right)^{\frac{\alpha-nd}{2}} \times K_{\alpha-nd}\left(2\sqrt{n\alpha\, tr(\mathbf{\Sigma}^{-1}\mathbf{C})}\right) \quad (4)$$

$$\Gamma_d(n) = \pi^{\frac{d(d-1)}{2}}\Gamma(n)\ldots\Gamma(n-d+1) \quad (5)$$

where α is the texture parameter, $\mathbf{\Sigma}$ is the expectation of the covariance matrix, d is the dimension of speckle vector, d=2, n is the number of looks, $\Gamma(\cdot)$ denotes the gamma function and $tr(\cdot)$ represents the trace of the matrix. $K_v(\cdot)$ denotes the modified Bessel function of the second kind with order v.

Based on the second moment, the texture parameter of the K distribution is expressed as:

$$\hat{\alpha}_D = \frac{d(nd+1)}{n\mathrm{Var}\{M\} - d} \quad (6)$$

where $M = tr(\mathbf{\Sigma}^{-1}\mathbf{C})$.

According to Eq. (3), there is a corresponding relation between the texture parameters and the variance of texture variable in product model. The larger the estimated texture parameters are, the smaller the variance of the texture variables become. Therefore, the texture parameters reflect the homogeneity of the targets. This paper proposed an effective way to distinguish between intact buildings and collapsed buildings using the texture parameters of statistical model.

2.4. Building Damage Assessment

Based on the estimated texture parameter, the collapsed buildings are extracted using the threshold which is determined by iterative method.

The building block collapse rate (BBCR) is calculated at the block scale. These blocks are separated by roads, and the structures of building have a strong similarity in one block [2]. BBCR is defined as the proportion of collapsed buildings to the total number of buildings (contains intact buildings and collapsed buildings) of the block. The more serious damage the block suffers, the greater BBCR is. The BBCR is expressed as:

$$\mathrm{BBCR}_j = \frac{NC_j}{NI_j + NC_j} \quad (7)$$

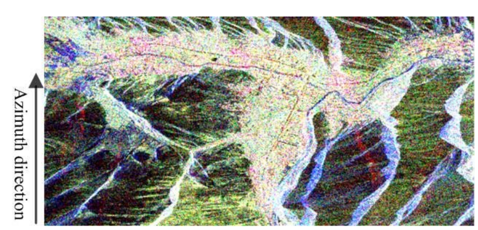
where NC_j and NI_j indicate the number of collapsed and intact buildings of the j th block. The thresholds $d1$ and $d2$ are set based on BBCR, and the blocks are divided into three levels: slight damage, moderate damage and serious damage.

$$\begin{cases} \text{if} \quad \mathrm{BBCR} \le \mathrm{d1}, & \text{the block} \in \text{slight damage} \\ \text{if} \quad \mathrm{d1} < \mathrm{BBCR} \le \mathrm{d2}, & \text{the block} \in \text{moderate damage} \\ \text{if} \quad \mathrm{BBCR} > \mathrm{d2}, & \text{the block} \in \text{serious damage} \end{cases} \quad (8)$$

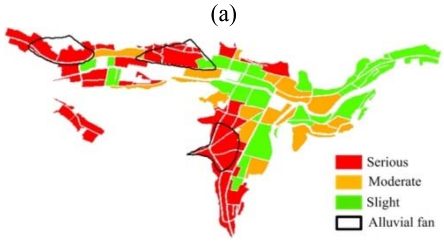
3. EXPERIMENTAL RESULTS

3.1. Experimental Data

The test site is Yushu County, Qinghai province of China, where a 7.1 magnitude earthquake occurred on April 14, 2010. There are collapsed/intact buildings, bare soil, sparse vegetation, rivers and roads in Yushu County. The full polarimetric data was obtained from RADARSAT-2 on April 21, 2010, with 8-m resolution, are shown in Fig. 2 (a). The reference map was interpreted according to the 0.5-m optical imagery acquired on May 6, 2010 and the detailed damage map from the DLR [8], as shown in Fig. 2(b).



(a)



(b)

Fig. 2. The test site of Yushu Country: (a) Pauli RGB of PolSAR data; (b) Reference map.

3.2. Results Analysis

In this paper, $d1$, $d2$ are set to 0.3 and 0.5 according to other studies [2,3] and our experience. Fig.3 (a) and (b) show the assessment result of the statistical model texture parameter of π/4 (SMTP_π/4) and HP mode (SMTP_HP) CP SAR, respectively. Fig.3(c) shows the assessment result of the statistical model texture parameter of PolSAR (SMTP_FP). The building damage assessment map of contrast texture of the gray level co-occurrence matrix of π/4 mode CP SAR (CG_π/4) is shown in Fig. 3(d). The differences between assessment map and reference map are shown in Fig.3 (e)-(h), which has three levels: Correct; The difference of one level (DOL); The difference of two levels (DTL).

The detection rate (DR), false alarm rate (FAR), F1-score and overall accuracy (OA) are used to evaluate the assessment accuracy, as shown in Table 1.

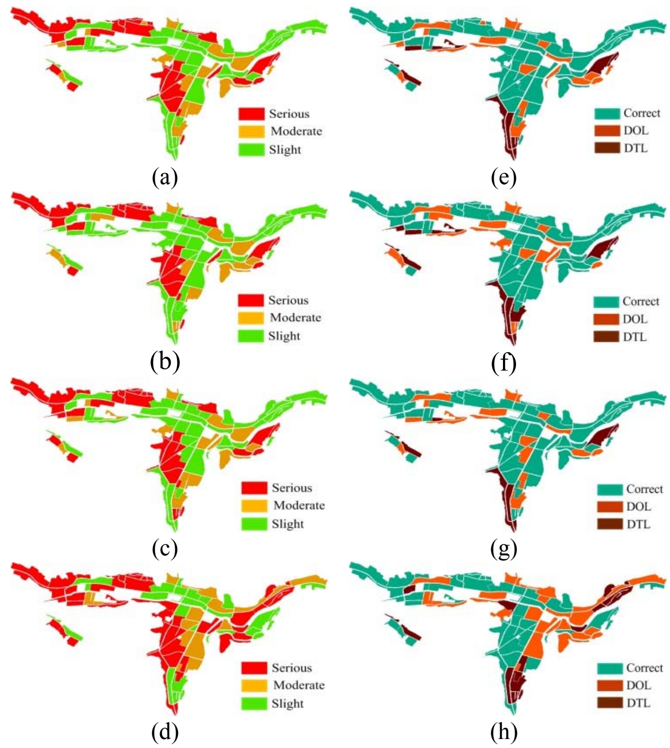


Fig. 3. The results of building damage assessment: (a) SMTP_π/4; (b) SMTP_HP; (c) SMTP_FP; (d) CG_π/4; (e)-(h) are the difference maps of (a)-(d), respectively.

Table 1. The accuracies of building damage assessment.

	Serious (%)			Moderate (%)			Slight (%)			OA
	DR	FAR	F1	DR	FAR	F1	DR	FAR	F1	
SMTP_π/4	71.89	13.88	78.37	52.19	31.35	59.30	86.27	37.51	72.48	71.99
SMTP_HP	67.07	11.91	76.15	47.99	28.25	57.51	91.23	40.71	71.87	70.59
SMTP_FP	75.14	12.01	81.06	51.69	32.48	58.56	87.62	35.21	74.49	73.70
CG_π/4	79.06	14.54	82.14	16.17	56.16	23.63	87.37	43.50	68.63	66.75

As shown in Fig. 3 and Table 1, the assessment result of CP SAR is very similar to that of PolSAR, but the evaluation accuracy of CP SAR is slightly worse than that of PolSAR. SMTP_π/4 is a better way to build damage assessment than SMTP_HP.

The assessment result of SMTP_π/4 is better than that of CG_π/4. As shown in Fig. 3(a), (d), (e) and (h), the method of CG_π/4 assesses most of the serious damaged blocks correctly, but parts of slight damage are wrongly assessed as moderate or serious damage. In particular, it is easy to misjudge some slight damaged areas in the northeast corner of the county as serious damage. As shown in Table 1, the method of CG_π/4 has high DR and FAR for serious damage and low F1-score (45.80%) for slight damage, and OA is 66.75%. Compared with CG_π/4, the result of SMTP_π/4 is more accurate, as shown in Fig. 3. (a) and (e), slight damage in northeast and the serious damaged areas on the three alluvial fans are assessed correctly, while some serious damaged areas in the southern and southwest are evaluated as moderate or slight damage. Compared with CG_π/4, SMTP_π/4 is more accurate in making damage assessment. The OA increases by about 5% and the F1-score of moderate damage increases by more than 25%.

4. CONCLUSION

In this paper, we proposed a new building damage assessment method using the statistical model texture parameter of compact polarimetric synthetic aperture radar. The results of RADARSAT-2 data in the Yushu County indicate that the method assess building damage effectively by comparing with other methods. Future work is to test this method on other compact polarimetric synthetic aperture radar data.

5. ACKNOWLEDGMENTS

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