Damage assessment in urban areas using post-earthquake airborne PolSAR imagery

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Published online: 22 Nov 2013.

To cite this article: Lingli Zhao, Jie Yang, Pingxiang Li, Liangpei Zhang, Lei Shi & Fengkai Lang (2013) Damage assessment in urban areas using post-earthquake airborne PolSAR imagery, International Journal of Remote Sensing, 34:24, 8952-8966, DOI: 10.1080/01431161.2013.860566

To link to this article: http://dx.doi.org/10.1080/01431161.2013.860566

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Damage assessment in urban areas using post-earthquake airborne PolSAR imagery

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(Received 27 December 2012; accepted 24 May 2013)

Synthetic aperture radar (SAR) has often been used in earthquake damage assessment due to its extreme versatility and almost all-weather, day-and-night capability. In this article, we demonstrate the potential to use only post-event, high-resolution airborne polarimetric SAR (PolSAR) imagery to estimate the damage level at the block scale. Intact buildings with large orientation angles have a similar scattering mechanism to collapsed buildings; they are all volume-scattering dominant and reflection asymmetric, which seriously hampers the process of damage assessment. In this article, we propose a new damage assessment method combining polarimetric and spatial texture information to eliminate this deficiency. In the proposed method, the normalized circular-pol correlation coefficient is used first to identify intact buildings aligned parallel with the flight direction of the radar. The ‘homogeneity’ feature of the grey-level co-occurrence matrix (GLCM) is then introduced to distinguish building patches with large orientation angles from the severely damaged class. Furthermore, a new damage assessment index is also introduced to handle the assessment at the level of the block scale. To demonstrate the effectiveness of the proposed approach, the high-resolution airborne PolSAR imagery acquired after the earthquake that hit Yushu County, Qinghai Province of China, is investigated. By comparison with the damage validation map, the results confirm the validity of the proposed method and the advantage of further improving the assessment accuracy without external ancillary optical or SAR data.

1. Introduction

Owing to their unpredictability, earthquakes can often severely damage people’s lives and properties. Infrastructure and communications are often destroyed after a major earthquake. Earth observation (EO) remote-sensing techniques are of great value to the early response and rescue activities involved with such destructive disasters. Optical and synthetic aperture radar (SAR) remote-sensing images have been widely studied to enable a rapid understanding of the general situation after an earthquake. High-resolution (HR) optical images, being relatively straightforward for investigating the impact of damage (Corbane et al. 2011; Kaya, Curran, and Llewellyn 2005; Lodhi 2013), are limited by night-time and inclement weather. SAR is therefore a valuable tool for damage interpretation, not only because of its nearly all-weather capability, but also because the back-scattering and phase are sensitive to ground changes.

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A number of approaches have been developed to explore the damage information carried by SAR imagery. The intensity changes (Chini, Pierdicca, and Emery 2009; Matsuoka and Yamazaki 2005; Yonezawa and Takeuchi 2001), coherence coefficient (Brenner and Roessing 2008; Hoffmann 2007), and the fusion of optical and post-event SAR imagery (Brunner, Lemoine, and Bruzzone 2010; Stramondo et al. 2006) have been used to assess damage levels. These methodologies achieve relatively reliable results in some cases of earthquake. However, the wide application of these methods is often subject to the collection of multi-temporal or multi-source data, especially for remote areas where the corresponding pre-event acquisition is often unavailable. For urgent events, evaluating damage by the use of only post-event SAR data is essential. To this end, Balz and Liao (2010) investigated the characteristics of layover, shadow, and corner reflections in struck urban areas for visual interpretation with respect to the earthquake that occurred in Wenchuan, China, on 12 May 2008. The spatial texture characteristics carried by post-event single polarimetric SAR (PolSAR) data have been presented in Cossu et al. (2012), Dell’Acqua and Gamba (2012), and Polli, Dell’Acqua, and Lisini (2010). These studies reported that the texture features in the HR constellation of small satellites for the Mediterranean basin observation (COSMO)-SkyMed images had some correlation with the damage level in the case studies of the L’Aquila (Haiti) and Wenchuan earthquakes. However, the large dispersion of texture for each damage level prevents the creation of a reliable evaluation map. Dell’Acqua et al. (2011) recently used external post-event optical data to exclude undamaged blocks to reduce dispersion, then the texture features in the SAR image were used to distinguish the different classes of damage.

With the ongoing development of SAR techniques, more and more missions could acquire PolSAR data, such as TerraSAR-X, Radarsat-2, and the future mission of the Advanced Land Observing Satellite (ALOS)-2. Some airborne sensors whose flight paths are more flexible can also acquire extensive data sets with high resolution and multi-polarization in a short period of time. PolSAR imagery can be complementary to other remote-sensing techniques, by providing rich information with three channels in the monostatic case. Changes in polarimetric scattering mechanisms in struck urban areas have been investigated by comparing pre-/post-event ALOS quad-pol SAR images from the 2011 East Japan earthquake (Chen and Sato 2013; Sato, Chen, and Satake 2012; Watanabe et al. 2012). These studies found that polarimetric parameters such as entropy, alpha, and orientation angle are sensitive to ground changes. Li et al. (2012) explored the potential of full polarimetric Radarsat-2 imagery for damage interpretation in a case study of the Yushu earthquake. However, the resolution of these spaceborne images is coarse, and it is worthwhile evaluating the performance of airborne HR PolSAR imagery for detailed damage-level assessment. In addition, a common problem existing in damage assessment is that built-up patches not aligned along the azimuth direction (oblique buildings, for short) are associated with similar scattering mechanisms to the collapsed buildings, which seriously hampers the process of damage assessment. Considering the low homogeneity of seriously damaged blocks, the spatial texture feature is introduced in the process of damage assessment to distinguish oblique patches from seriously damaged blocks. To circumvent the large dispersion of texture, polarimetric information, which is sensitive to shape and orientation, is explored to first exclude parallel building patches with strong double scattering.

This feasibility study was performed on the post-event HR airborne PolSAR data of the Yushu earthquake, with the aim of obtaining a damage map with three levels at the block scale.
2. Polarimetric and texture feature stacking algorithms

2.1. Polarimetric characteristics of a stricken area

2.1.1. H-α-Wishart unsupervised classification algorithm

H-α-Wishart is a robust unsupervised classification algorithm proposed by Lee et al. (2004) that is based on H/α target decomposition (Cloude and Pottier 1997). The entropy H measures the randomness of scattering mechanisms, and α characterizes the scattering mechanisms. Physical scattering characteristics associated with each zone on the H/α plane provide information for terrain type assignment. According to Jager et al. (2007) and Marino, Cloude, and Woodhouse (2012), the Wishart classifier has strong dependence on the intensity of the backscattering. Targets with weak backscattering such as road, bare soil, water, etc., are easily classified into the odd scattering classes. The pixels falling into these classes, which correspond to the Z6 and Z9 segments of the H/α plane, are regarded as non-buildings; the remainder are considered as debris or intact buildings. Although the urban area no longer complies with the Wishart distribution, we make use of the weak backscattering scatterers to avoid the setting of a threshold and do not consider the overall classification accuracy.

2.1.2. Yamaguchi four-component scattering model

Yamaguchi decomposition (Yamaguchi et al. 2005), which is more suitable for urban environments, models the covariance or coherence matrix \( \langle T \rangle \) as the contributions of four scattering mechanisms: surface scattering (odd), double-bounce scattering (dbl), volume scattering (vol), and helix scattering (helix):

\[
\langle T \rangle = P_s \langle T_{od} \rangle + P_d \langle T_{dbl} \rangle + P_v \langle T_{vol} \rangle + P_h \langle T_{helix} \rangle,
\]

where \( P_i \) corresponds to the scattering power of each component, and \( \langle \rangle \) is the sample averaging operator. The model for each component and the decomposition algorithm are described in Yamaguchi et al. (2005).

The double-bounce scattering power is particularly strong for parallel buildings whose walls form a ‘dihedral reflector’ with the ground. However, if the building is damaged, the ‘dihedral reflector’ will not be kept, leaving debris with a random spatial arrangement and orientation. Meanwhile, the reflection symmetry is also disturbed for collapsed buildings in the plane orthogonal to the radar line of sight, resulting in the domination of volume scattering.

However, the oblique buildings induce significant cross-pol backscattering and lack reflection symmetry, which is similar to collapsed buildings. In conventional polarization analysis, it has proved a challenging topic to discriminate oblique buildings from vegetation areas (Jager et al. 2007). Polarimetric orientation angle compensation (Kimura 2008; Yamaguchi et al. 2011) and several other skilful decomposition schemes have been developed to improve the double scattering power of oblique buildings (Chen et al. 2013; Singh, Yamaguchi, and Park 2013), but they incur some difficulty when dealing with patches characterized by large orientation angles. In addition, there are more complex structures in a disaster situation, where many damaged buildings create chaotic orientation angles with no regular pattern.
2.1.3. Normalized circular-pol correlation coefficient

The normalized circular-pol correlation coefficient (NCCC) is an efficient feature index for reflection-asymmetric structures (Ainsworth, Schuler, and Lee 2008) and can be expressed as

$$\text{NCCC} = \left| \frac{\rho_{RR\overline{L}L}}{\rho(0)} \right|,$$

where

$$\rho_{RR\overline{L}L} = \frac{\langle S_{RR} S_{LL}^* \rangle}{\sqrt{\langle S_{RR} S_{RR} \rangle} \sqrt{\langle S_{LL} S_{LL}^* \rangle}}$$

is the correlation coefficient of the right–right (RR) and left–left (LL) polarimetric channels in the circular polarimetric basis and * stands for conjugate operator. The transformation from the linear to the circular basis is as follows:

$$S_{RR} = iS_{hv} + \frac{1}{2}(S_{hh} - S_{vv}),$$
$$S_{LL} = iS_{hv} - \frac{1}{2}(S_{hh} - S_{vv}),$$

where, $S_{hh}$, $S_{hv}$, and $S_{vv}$ are the scattering matrix elements in the horizontal (h)–vertical (v) polarimetric basis;

$$\rho(0) = \frac{\langle |S_{hv}|^2 - |S_{hh} - S_{vv}|^2 \rangle}{\langle |S_{hv}|^2 + |S_{hh} - S_{vv}|^2 \rangle}$$

is achieved under the reflection symmetry condition, namely $\langle S_{hv}^* S_{hh} \rangle \approx \langle S_{hv}^* S_{vv} \rangle \approx 0$. The image part of $\rho_{RR\overline{L}L}$ is larger for reflection-asymmetric scatterers, and so is the NCCC that gives prominence to collapsed and oblique buildings. Ainsworth, Schuler, and Lee (2008) illustrated its effectiveness for reducing many of the unneeded image details of backscattering variations from natural areas of different surface roughness. Moreover, it has a better description capability for cross-pol ($S_{hv}$) scattering (Yamaguchi et al. 2008), particularly allowing for the circumvention of confusion between vegetation areas and collapsed buildings, without the assistance of external data such as the normalized difference vegetation index (NDVI). This is crucial for the reliable damage assessment of stricken regions.

2.2. Texture feature GLCM

Texture is one of the notable characteristics of HR remote-sensing imagery. The grey-level co-occurrence matrix (GLCM) (Haralick, Shanmugam, and Dinstein 1973) is established as a standard technique for extracting texture features; it is a tabulation of how often different combinations of grey levels co-occur in an image section and describes the second-order statistical relationships of two pixels. The ‘homogeneity’ (Hom) feature was chosen for the co-occurrence matrix:

[Insert Equation]
\[ \text{Hom} = \sum_i \sum_j \frac{P(i,j)}{1 + (i - j)^2}, \]  

where \((i,j)\) are the coordinates in the co-occurrence matrix space and \(P(i,j)\) is the element at \((i,j)\) of the normalized symmetrical GLCM. It indicates the heterogeneity of the local area and represents a smoothness approaching 1.

There are often heaps of rubble around collapsed buildings, whose Hom feature is usually smaller than the non-damaged regions. Roads in collapsed patches show a low Hom, because of being occupied by rubble. However, roads and shadows in oblique patches show extreme smoothness, and this improves the mean Hom feature for these patches. The correlation between the Hom feature and damage level has been investigated using single polarimetric COSMO-SkyMed or advanced SAR (ASAR) data, in the case studies of the L’Aquila and Wenchuan earthquakes (Cossu et al. 2012; Dell’Acqua et al. 2011; Dell’Acqua, Gamba, and Polli 2011). These studies showed that texture in a SAR image is a good indicator of different damage levels, but it has limited capacity to discriminate between damaged and non-damaged blocks.

3. Damage assessment framework

According to the previous analysis, the polarimetric and texture features are combined in the proposed damage assessment framework with the focus on improving the damage assessment accuracy for built-up patches that are not aligned with the flight direction. Reflection-asymmetric scatterers, namely collapsed buildings and oblique buildings, are detected first by NCCC then the Hom feature of GLCM is used to distinguish the oblique building patches from the seriously damaged class.

3.1. Damage-level index

Owing to the complexity of the urban environment and the effect of layover and speckle noise, it is hard to achieve a homogeneous result or detect directly the footprint of a single building from a PolSAR imagery. Therefore, in this case, the block aggregation concept is adopted. Generally, urban roads represent ruptures of the whole area. The parcels separated by roads are then regarded as individual areas of similar building structure.

Each building patch is assigned a level by the proposed damage-level index (DLI):

\[ \text{DLI}_j = \frac{\sum_i d_{ij} P_{ij}}{A_j - B_j}, \]  

where

\[ \text{DLI}_j \] is the DLI of the \( j \)th polygon;
\[ d_{ij} \] indicates whether the pixel \( i \) in the \( j \)th polygon belongs to a damaged building or not, with values of 0 or 1;
\[ P_{ij} \] indicates whether the pixel \( i \) belongs to the building area of the \( j \)th polygon, with values of 0 or 1;
\[ A_j \] is the total number of pixels in the \( j \)th polygon; and
\[ B_j \] is the total non-building pixels of the \( j \)th polygon.
DLI is a new index that is unlike the more generally used damaged area ratio (DAR) (Dell’Acqua et al. 2011), which considers the whole area as the building footprint. If one polygon has few buildings and more non-building targets, such as bare soil, its damage level will be underestimated using DAR. DLI mitigates the effect of non-building targets on damage assessment, being more suitable for areas with sparse buildings.

3.2. Process flow of damage assessment

Figure 1 shows the basic process flow in the proposed damage assessment framework. The procedure is as follows:

Step 1. Filter the PolSAR data to suppress the level of speckle noise.
Step 2. Extract the non-building pixels by $H$-$\alpha$-Wishart unsupervised classification performed on the coherency matrix.
Step 3. Detect collapsed buildings from the remaining pixels using the polarimetric parameter NCCC. If the value is larger than the threshold, assign it to the collapsed class; otherwise, assign it to the intact class. The optimal threshold is determined by the statistical histogram.
Step 4. Assess the damage level for each polygon by DLI to acquire a preliminary damage evaluation map. The damage level is a continuous value ranging from 0 to 1. Two thresholds are set to split it into three damage levels, namely slight damage (SD), median damage (MD), and serious damage (SSD).
Step 5. Compute the Hom texture feature of GLCM on the span image that is the sum of the diagonal elements of the coherency matrix.
Step 6. Based on the preliminary evaluation map, the inaccuracy caused by oblique buildings is corrected by the Hom feature. The correction is performed only on polygons labelled as SSD. If the Hom of the block is larger than the settled threshold $T_h$, assign it to the MD level; otherwise, keep it as the SSD level. The decision rule is as follows:

$$
\begin{cases} 
P_i \in \text{MD}, & \text{if } P_i \in \text{SSD} \& \text{HOM} \geq T_h \\
P_i \in \text{SSD}, & \text{if } P_i \in \text{SSD} \& \text{HOM} < T_h \\
\text{no change}, & \text{if } P_i \notin \text{SSD},
\end{cases}
$$

where $P_i$ is the $i$th polygon and $T_h$ is the Hom feature threshold fixed by experience. Finally, we obtain the final damage assessment map with three damage levels.

![Figure 1. Overview of the damage assessment framework.](image)
4. Experiments on post-event airborne PolSAR data, and discussion

4.1. Experimental data

In order to validate the effectiveness of the proposed damage assessment algorithm, experiments were conducted on the PolSAR imagery of the Yushu earthquake. Figure 2(a) illustrates the epicentre, which was at 33° 06′ N, 96° 42′ E. This moment magnitude (Mw) 6.9 earthquake occurred on 14 April 2010, in Yushu County, Qinghai Province of China, causing serious damage to the county. A large number of buildings collapsed, with more than 2600 fatalities and many made homeless. The airborne PolSAR data set was acquired in the P band by the Chinese domestic airborne mapping system SARMapper on 15 April, with a spatial resolution of approximately 1 m in range and azimuth. The flight altitude was about 10,079 m, and the central incidence angle was about 50°. The Pauli RGB image is shown in Figure 2(b), as a colour composite of | HH + VV | (blue), | HH − VV | (red) and | HV | (green). To suppress speckle noise, a refined Lee filter (Lee, Grunes, and de Grandi 1999) with a window size of seven was applied. Yushu County has an elevation of about 3500 m and is surrounded by mountains. Since the image size was huge (7984 × 8192 pixels), mountains around the city were excluded to focus the analysis on the urban area.

To obtain the ground truth, we integrated the map taken from the International Charter on Space and Major Disasters (ICSMD 2010) and the result interpreted manually by Guo et al. (2010) from an aerial image with a spatial resolution of 0.33 m. A GIS layer containing 69 polygons was outlined manually, according to the main roads. This approach can better capture the damage patterns by grouping urban areas that have similar building types, construction materials, and geophysical characteristics of soils, rather than a grid-based representation (Corbane et al. 2011). The damage levels were translated into three damage classes at the block level, as shown in Figure 3.

4.2. Polarimetric and ‘homogeneity’ features

Three regions of interest (ROIs) in Figure 2(b) are selected to facilitate the comparison of the different features. ROI I includes intact buildings aligned parallel to the flight direction, ‘parallel buildings’ for short; ROI II is a significantly damaged built-up area,
while ROI III mainly contains ‘oblique buildings’ that are not aligned to the along-track direction.

Non-building scatterers detected by the unsupervised $H$-$\alpha$-Wishart classification algorithm are shown in Figure 4 in red. Bare soil, major roads, rivers, etc., belonging to odd scattering are well recognized. Figure 5 shows the relative contribution of different scattering mechanisms by Yamaguchi four-component decomposition for the three ROIs. The double-bounce scattering power is particularly strong for parallel buildings and is low for the collapsed and oblique buildings that are all volume-scattering dominant and reflection asymmetric. The larger helix component of the collapsed and oblique building patches indicates complex scattering environments in these two types of area.

Figure 6(a) shows the NCCC of the PolSAR data, from which we can see that reflection-symmetric targets such as parallel buildings, rivers, and bare soil all have a low value while collapsed buildings and oblique buildings, being reflection asymmetric, all have relatively high values. The statistic histogram of the polarimetric parameter for the three ROIs is shown in Figure 6(b). The red line corresponds to the upper edge of the statistic bars for the oblique buildings, and it has a similar tendency to the collapsed buildings (in blue). The left part of the histogram is the probability distribution of the parallel buildings, and it is well separated from the right part. The decision threshold is fixed at 1.8 to allow discrimination of the reflection-asymmetric structures.

The polarimetric decomposition components and NCCC reveal that the physical scattering mechanism is notably different between collapsed and parallel buildings, the
same conclusion reached by Sato, Chen, and Satake (2012) and Li et al. (2012), but it is not sufficient for collapsed buildings and oblique patches. The Hom texture feature is computed with a window size of $11 \times 11$ and a $\Delta x = \Delta y = 3$ shifted pixel. The averaged texture at the polygon scale ranges from 0.2105 to 0.851 in Figure 7. According to the damage truth map, the relationship between damage levels (horizontal axes) and texture value is shown in the scatter plots in Figure 8. We can see how the texture values of these polygons are distributed for each damage level. The bottom of each vertical bar shows that the higher the level is, the lower the texture is. However, there is a large dispersion for each damage level. For the slightly damaged patches, the large dispersion is mainly due to the various densities of buildings in these patches. Blocks with a low density of buildings tend to have a large Hom feature, and the inverse applies to blocks with a high density. For severely damaged blocks, the large dispersion is mainly due to the various densities of buildings in these patches. Blocks with a low density of buildings tend to have a large Hom feature, and the inverse applies to blocks with a high density.

Figure 5. Relative contribution of the scattering mechanisms derived from Yamaguchi decomposition.

Note: odd, surface scattering; dbl, double-bounce scattering; vol, volume scattering; helix, helix scattering; Ratio, relative contributions of scattering mechanisms.

Figure 6. (a) NCCC of the Yushu urban area; (b) statistical histograms of the three ROIs. The red line denotes the upper edge of the statistical bars of oblique buildings, the green area is the histogram of parallel buildings, and blue corresponds to collapsed buildings.
dispersion is mainly due to non-building objects such as farmland. It is, however, intractable to determine the damage level for polygons with large texture values that may belong to an arbitrary damage level.

To reduce the effect of the large dispersion of texture on damage assessment, intact parallel building blocks are discriminated first in the polarimetric space, and the collapsed and oblique building patches remain undetermined. In general, oblique building patches often have a larger averaged Hom than severely damaged patches. The texture threshold $T_h$ is fixed as a median value of 0.5, to place the blocks recognized as ‘seriously damaged’ in the preliminary assessment map into either the MD or SSD level.

4.3. Damage assessment results

Figure 9 is the preliminary damage assessment map in DLI, based on rudimentary detection. The larger the DLI is, the higher the level of damage becomes. The two thresholds are then set as 0.3 and 0.5, based on experience, and the evaluation map with three damage levels is shown in Figure 10. It is evident that the damage tendency generally agrees with the ground truth, especially for the slightly damaged parallel patches. However, some blocks (11 out of 27) inherently belonging to the MD class were significantly overestimated. In these blocks, there are some collapsed buildings and

Figure 7. The averaged Hom feature by block partition.

Figure 8. Scatter plots of the Hom feature for each damage level.
more intact buildings of large orientation angle. The high NCCC values of the oblique buildings seriously hamper the process of damage assessment.

Figure 11 is the damage evaluation map created by the proposed approach combining polarimetric and texture features. Nine of the eleven overestimated patches are again classified into the MD class. The remaining two patches, labelled A and B in Figure 10, are not corrected due to compact buildings of high density. Table 1 shows the quantitative assessment accuracy based on polygons for damage evaluation, before and after introducing the texture. The overall accuracy improved from 73.9% to 79.7%, and the kappa coefficient increased to 0.683 from 0.590. This confirms that the Hom texture feature is suitable for distinguishing oblique from collapsed buildings, on the premise that intact parallel patches have first been excluded. This can be regarded as supplementary information for the polarimetric feature space in damage assessment using post-seismic PolSAR imagery.

It should be noted that the five patches labelled 1–5 are underestimated by the proposed approach. These blocks are often far from the town, with a small population and few buildings. Although some of them are classified correctly at the preliminary assessment stage in the polarimetric space, the larger Hom feature results in a biased estimation at the emendation stage.
4.4. Discussion

NCCC, texture, and damage-level segment thresholds must be determined by the proposed method. The NCCC threshold indicates whether a target is symmetric or non-symmetric. The values of the symmetric targets are concentrated at low values, while there is a large variance for asymmetric targets. An accurate and reliable method under a non-Gaussian assumption still needs to be developed to make this determination automatic.

Building patches of large orientation angle generally have a larger Hom texture than polygons with collapsed buildings. The ‘Hom’ texture threshold is set at a pre-determined value of 0.5 in the proposed method, which was chosen as the indicator of ‘large’ or ‘small’.

Issues remain in terms of finding suitable thresholds for damage classification, because a clear damage assessment scale referring to Earth observation (EO) data has not yet been defined. In addition, the EO-based damage scale depends on data type and spatial resolution. Different selection methods for the polygons also have some influence on damage assessment, but there is only a small fluctuation in DLI at different polygon scales. Figure 12(a) shows the damage evaluation map in DLI using polygons at a fine scale. The evaluation map segmented into three damage levels by the same thresholds of 0.3 and 0.5 is shown in Figure 12(b). These maps show that the damage pattern is generally similar to the results using a coarse scale shown in Figures 9 and 10. It is revealed that the selection of polygons is not the most critical factor that hampers the process of damage assessment, rather building patches of large orientation angle. They all have significantly large DLI at different polygon scales, as shown in Figures 9 and 12(a), and this is the focus of this article.

Table 1. Comparison of damage assessment results by employing different features.

<table>
<thead>
<tr>
<th>Truth map</th>
<th>Polarimetric feature</th>
<th>Polarimetric and texture features</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SD</td>
<td>MD</td>
</tr>
<tr>
<td>SD</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>MD</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>SSD</td>
<td>2</td>
<td>11</td>
</tr>
</tbody>
</table>

OA = 73.9%, kappa coefficient = 0.590
OA = 79.7%, kappa coefficient = 0.683
5. Conclusion

A promising damage assessment approach at the block scale using only post-earthquake HR PolSAR data has been developed. The combination of polarimetric and spatial texture features eliminates the deficiency where intact building patches of large orientation angle are confused with collapsed buildings. The exclusion of symmetric targets, such as parallel buildings, using the polarimetric parameter NCCC reduces the dispersion of texture for different damage levels. The ‘Hom’ texture feature is demonstrated as being fit for distinguishing both intact oblique and collapsed building patches. Overestimation of the damage level for building patches of large orientation angle is mitigated, without the assistance of optical or pre-event SAR data.

An acceptable overall accuracy is achieved for the Yushu urban area, indicating the potential of HR PolSAR data in damage assessment. Furthermore, HR airborne imagery provides a flexible option for damage assessment compared with the use of spaceborne SAR data. This could be particularly important when remote-sensing data are scarce. In future, we will focus on determining thresholds automatically and undertaking damage assessment in a multi-scale way to achieve a more reliable assessment result.

Acknowledgements

The authors would like to thank the anonymous reviewers for their constructive comments and the Chinese Academy of Surveying & Mapping (CASM) for providing the necessary quad-pol data sets.
Funding
The work was supported by the 863 High Technology Programme of China [grant number 2011AA120404]; the National Natural Science Foundation of China [grant number 61371199]; and the Fundamental Research Funds for the Central Universities [grant number 2012619020213], [grant number 2012619020206].

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