EXPERIENCES IN OPTICAL AND SAR IMAGERY ANALYSIS FOR DAMAGE ASSESSMENT IN THE WUHAN, MAY 2008 EARTHQUAKE

F. Dell’Acqua\(^{(1)}\), G. Lisini\(^{(2)}\) and P. Gamba\(^{(1)}\)

(1) Department of Electronics, University of Pavia
Via Ferrata, 1 - I-27100 Pavia, Italy
(2) Center for Research on Risk and Security - Institute for Advanced Studies (IUSS)
Lungo Ticino Sforza, 56 – I-27100 Pavia, Italy

Corresponding author: paolo.gamba@unipv.it

ABSTRACT

The Sichuan Earthquake on the 12th of May 2008, and the extensive rescue operations following this tragic event, proved the value of high-resolution optical and radar remote sensing during the emergency response. Optical data provide a fast and simple way to value “at glance” damages while radar sensors can deliver images independent of weather conditions, day and night, and thus in principle can represent a mean to obtain a damage map in the immediate aftermath of an event, providing precious information for intervention planning. On the other hand, SAR data is far more difficult to interpret than optical data both to the expert and non-expert.

In this paper we present a case study of damage assessment on the Sichuan earthquake experimenting the use of very high resolution data from both worlds, discussing preliminary results and perspectives.

In sect. 2 we will present some hypothesis and experiments we have performed, aimed at damage assessment relying only on post-event images. In sect. 4 some preliminary conclusions will be drawn and sect. 5 will present some direction of future development.

2. HYPOTHESIS ON POST-EVENT SAR DATA

The appearance of undamaged buildings in SAR images typically consist of three identifiable areas:

- layover area, with a strong reflection due to double bounce of electromagnetic waves;
- roof area, with a reflection depending on roof roughness, shape and features;
- shadow area, weak reflection

Each of the three areas is expected to show some degree of inherent homogeneity, which is assumed to disappear or at least significantly decrease when the building is sufficiently damaged to change its apparent shape. In this latter case, indeed, the double bounce area is expected to persist only on extant portions of walls, while new corner cube structures are expected to appear within the footprint of the building where cracks in the structure—or even pieces of wall in case of collapse—cause local double reflection of the incoming electromagnetic wave. The resolution currently achievable should allow discriminating such details. In the case of damaged buildings, thus, a lower homogeneity level is expected. Block-scale assessment seems to be more effective than pixel-level assessment and evaluation will be made at the former level.
3. EXPERIMENTS

3.1. VHR Optical data

A sample of the original, registered images is shown in Figure 1.

![Figure 1: pre- (left) and post-event (right) QuickBird image crop on the selected site.](image1)

A change detection was performed by running two separate classifications using an ARTMAP neural network formerly used within the research group [5]. This step was followed by a procedure to reduce the set of classes to just two final classes: “building” and “non-building” (see Figure 2). Each cluster of “building” pixels was recognized as an object and labeled accordingly. A hypothesis is made that a collapsed building should produce one more clusters of debris, i.e. “building” pixels, given their similar matter composition and thus their spectral similarity with the original buildings.

![Figure 2: map of building pixels, shown in white on black background, in the (left) pre- and (right) post-event image.](image2)

Next, for every object (i.e. building) in the pre-event image a search is performed in the corresponding location in the post-event image to locate possibly corresponding objects (i.e. the same building or debris clusters) within a search area around its original location.

Based on the overlap area percentage, post-event objects are matched with the original pre-event building. The final goal, not yet implemented, is to evaluate the damage level based on the differences between the original pre-event object and the matching set of post-event objects.

The effectiveness of the algorithm was tested by evaluating how many post-event objects were correctly matched with each pre-event object (i.e. building, assuming no damage is reported until the single earthquake event in the studied area). This resulted in the following figures:

- 55% of pre-event buildings have been correctly matched with post-event objects
- 85% of pre-event buildings have been correctly matched with at least 75% of the actually corresponding post-event objects
- 15% of pre-event buildings have been matched with completely wrong objects

The next step consists of evaluating the change in location, shape and area of the matched objects as clues of earthquake-induced damage. Though, the method is still being tuned, and no reliable results are available yet.

3.2. VHR SAR data

Immediately after the Sichuan earthquake we activated two mechanisms we had available to collect data:

- within the European Centre for Training and Research in Earthquake Engineering, a “knowledge centre” of the Italian Civil Protection Department, our Group was enabled to access COSMO/SkyMed data acquired over the affected area;
- our research group is entitled to apply for TerraSAR-X data for scientific use following the acceptance of a project proposal connected to urban area mapping submitted in response to a DLR AO

SAR images from the two sources were partly overlapping including the city of Guan Xian (Dujiangyan), hardly hit by the disaster. This was chosen as the experiment site.

There may be various co-occurrence texture measures capable of telling homogeneous from inhomogeneous areas. Though, the closest to the concept expressed in the former section is probably the GLCM (Gray Level Co-occurrence Matrix) homogeneity measure. Homogeneity was thus computed over both images for different sizes of the sliding window and displacement:

- 21×21 pixel window, Δx=Δy=+3 pixels
- 21×21 pixel window, Δx=Δy=+11 pixels
- 51×51 pixel window, Δx=Δy=+21 pixels

Given the preliminary nature of the experiment no optimization was taken into consideration but rather a first guess was made of the possible scale at which inhomogeneity may appear in damaged areas. At a Ground Sampling Distance of 1 m, the chosen displacement...
measures do compare well with the typical size of buildings in an urban area.

City blocks were then outlined manually and texture measures were then averaged over each city block to produce a single summarizing figure whose correlation with the damage level of that block was later evaluated. A visual representation of results is provided in Figure 3, where the values of homogeneity are color-coded from the lowest (reddish colors) to highest (greenish colors).

![Figure 3: color-coded homogeneity measure on the COSMO/SkyMed image (left) and on the TerraSAR-X image (right).](image)

Ground truth (GT) data was extracted from a map [6] issued by the International Charter on Space and Major Disasters [7], and reports three different damage levels. The damage levels on the city blocks, verbally labeled in the original GT map, were translated into integer values increasing with worse damage levels. Next the correlation between the damage level and the texture measure averages over the series of city blocks were computed. Results are reported in Table 1. It can be noted that:

- The sign of the correlation coefficients is in agreement with the hypothesis made (the stronger the damage, the lower the homogeneity)
- Although the absolute value of correlation coefficients is somehow low, it is not negligible;
- The absolute value tends to increase with the window size

<table>
<thead>
<tr>
<th>Window size, displacement</th>
<th>COSMO/SkyMed (C/S)</th>
<th>TerraSAR-X (TSX)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21x21, d=+3,+3</td>
<td>-0.211</td>
<td>-0.008</td>
</tr>
<tr>
<td>21x21, d=+11,+11</td>
<td>-0.222</td>
<td>-0.156</td>
</tr>
<tr>
<td>51x51, d=+21,+21</td>
<td>-0.246</td>
<td>-0.183</td>
</tr>
</tbody>
</table>

Table 1: correlation coefficients between damage levels and texture measures. Left, COSMO/SkyMed data; right, TerraSAR-X data.

In evaluating those correlation coefficients, one should also take into account the very rough subdivision of damage levels. This adds up an amount of inherent quantization noise to the actual mismatch between the two variables.

4. PRELIMINARY CONCLUSIONS

4.1. Optical data

Preliminary results suggest that the proposed procedure is actually capable of preparing detection of earthquake-induced changes, especially in terms of matching pre- and post-event objects. Yet a comprehensive assessment of result reliability is still to be performed.

4.2. SAR data

According to the first outputs, the coefficients expressing correlation between block-averaged texture measures and damage levels appear to reveal a weak relationship between them. The coefficient always take negative values, which is in agreement with the hypothesis of decreasing homogeneity with increasing severity and extensiveness of the damage.

Though, the absolute values do not reach beyond 0.25. Some of the reasons contributing to a lower value even in presence of the hypothesized link between the two variables may be:

- A very rough subdivision into 3 damage levels (actually, 2 “damaged” + 1 “undamaged”), which somehow “hides” smaller --yet relevant-- differences possibly recorded by the texture measure
- Disturbing factors not accounted for in the image data, like e.g. local incidence angle or terrain slope, which may vary across the image. In the best correlation case (-0.246 in Table 1), if one restricts the correlation computation to the bottom half of the blocks in the figure, the correlation coefficient leaps to -0.41; this may naturally be due to pure chance, still it is worth being investigated.
- Finally, the damage map was obtained by visual interpretation of near-nadiral optical satellite data, which may have not made it possible to ascertain lower levels of damage, which do not manifest themselves so clearly in such images. Extensive ground-truthing operations would be required for a better assessment of the correlation.

5. FORESEEN DEVELOPMENTS

On the side of optical data, the next step will be using the established matching between pre- and post-event objects to evaluate the rate of change as an indicator of the damage level to the considered buildings. On the side of
SAR data, the absolute values of correlation encouraged us to further investigate for possible links between statistical features and damage levels. One of the main weak points so far is the limited size of the sample over which the correlation has been computed (one image, 56 blocks); similar experiments are however in progress on the L’Aquila, Italy, event and the preliminary outcome seems to confirm the figures found here. More intensive experimentation will be made, in particular:

- Testing the performance of homogeneity, as a damage indicator, with different GLCM window sizes; this implies addressing the issue of chasing higher correlations at the expense of using windows covering larger and larger portions of neighboring blocks.
- Testing different texture measures for possibly higher correlations.

Another important progress will be connected to obtaining ground truth data from in-situ inspection, providing a more reliable reference with respect to interpretation of near-nadiral satellite data, which tends to conceal weaker levels of damage to the buildings.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the Italian Civil Protection Department (DPC, Dipartimento della Protezione Civile) and the Italian Space Agency (ASI, Agenzia Spaziale Italiana) in providing the COSMO/SkyMed images over the Sichuan earthquake area, and the DLR for providing the TerraSAR-X image.

REFERENCES