Parcel-based Damage Detection
using VHR Optical Data

Babak Mansouri, Mehdi Mousavi,
and Kambod Amini-Hosseini
Risk Management Research Center
International Institute of Earthquake Eng. and Seismology
Tehran, Iran
mansouri@iiees.ac.ir

Masanobu Shinozuka
Dept. of Civil and Environment Engineering
University of California, Irvine
California, USA
shino@uci.edu

Abstract—Optical remote sensing has gained major technology breakthroughs and outstanding merits in monitoring the urban areas in disaster conditions. However, any change detection procedure must be checked for its level of sensitivities to different aspects of the phenomenon, materials and aspects of changes. So far, pixel-based and object-based image processing algorithms have been well received and utilized for major disasters around the world. These results are more useful in rapid loss estimation schemes right after a major disastrous event but baring in mind that these schemes are relatively imprecise.

Considering the fact that using urban parcel information improves the quality of the damage detection results, this research focuses on incorporating a city parcel database with a novel optical change detection algorithm. The parcel information is developed from the city CAD files (for BAM). The parcels are extracted from stereo aerial photos and modified with a manual process using very high resolution optical data in GIS. Our optical change detection algorithm takes into account different spectral and spatial features of the panchromatic band of Quickbird satellite data. A fuzzy logic methodology is then applied at the end of the process to identify the changes. The final results are then compared with direct visual damage observation of the building using VHR data.

I. INTRODUCTION

Remote sensing and GIS technologies have been progressively advanced and routinely exploited in rapid disaster damage assessment for the purpose of disaster management. Very High Resolution (VHR) optical imagery has provided highly spatial accurate images that can reveal adequate details of the built environment for the purpose of manual or automated building change/damage detection. Two major techniques namely pixel-based and object-based have been well studied and reported for urban change detection. Generally, pixel-based techniques are simpler and create less accurate results. In order to reduce the image processing errors, it seems that selecting only the pixels that represent the buildings is advisable. Recent advanced image processing computer codes can delineate between different objects of the scene and classify them. For example, in E-cognition computer code, although the final process is automated, but it requires some human interference with the machine in order to decide about setting different thresholds value for some of the feature parameters. Moreover the process of distinguishing between objects is not necessarily reliable. Alternatively, if there is a possibility in using urban ancillary data such as the building stock geodatabase, more accurate results can be produced in the damage assessment phase. The ancillary data used in this research is obtained from digital 1:2000 scale maps.

The case of Bam earthquake (December 23, 2003) is of focus in here since a collection of remote sensing data, such as optical VHR data, and different urban maps and statistics are available for before and after event. Also many researchers have already devised successful image processing methodologies in assessing the earthquake-induced changes to the area and it is beneficial to incorporate those findings. Moreover the urban setting in Bam is somewhat common in entire Iran and any new development in remote sensing rapid damage assessment schemes helps in creating and modifying a national disaster protocol applicable to the entire country.

Some of the adequate spectral and spatial features that were reported successful in urban change detection were exploited here. Some related works were reported by Huyck et al. [1], Rathje et al. [2] and Dell’Acqua et al. [3]. The spectral change detection is selected as the correlation between the before and after images, whereas the spatial changes are assigned as the difference in edge densities. It is statically shown that there is no significant correlation in between these features using the above images; therefore, the mentioned two features are considered independent. A fuzzy inferencing technique applies on the feature data to assess and classify the urban damages. The result is then compared with the direct observation and
The classification of the damage that was performed using the Quickbird image (Yamazaki et al. 2005) [4].

II. METHODOLOGY

The methodology has three major steps. Firstly, the before and after panchromatic Quickbird images in addition to the geodatabase parcel record are preprocessed and coregistered. Then suitable spectral and spatial features are selected as to pronounce the building physical levels of change/damage. These features are assigned a specific fuzzy membership relationship. Next, in accordance with a combined fuzzy change detection scheme, a classification rule applies to the parcel vector layer and a decision is made related to three levels of building damages. Figure 1 describes the steps.

A. Ancillary data – Parcel Information

The urban parcel information is created and entered in GIS for the city of Bam. The building stock geodatabase is created from the 1:2000 scale digital aerial stereography maps that were acquired (on 1993) before the 2003 Bam earthquake. These maps were registered with the VHR Quickbird data used in this research. The parcel layer was updated visually by the VHR Quickbird image. Figure 2 shows a portion of this data that has been GIS-ready and comprises of city parcel records pronouncing the building footprints and building heights.

B. Remote Sensing data - VHR Quickbird data

The remote sensing data used in here are two panchromatic Quickbird data acquired on September 30, 2003 and January 03, 2004. Figure 3 shows a portion of these files where the parcel vectors (building mask) are overlaid on the top.

C. Change Detection Elements

The basic step in change detection in each parcel is to select the indices or the features that describe effectively the physical changes to the buildings. By visual observation it is perceived that destroyed building shows strong reduction in reflection characteristics. Therefore it is hypothesized that the spectral characteristics of the imagery band (before and after panchromatic band of Quickbird) in use vary in relation with physical changes. The spectral correlation is selected as a feature to detect these changes. As for the spatial feature, the density and the spatial distribution of the edges (directional pixel gradient) change as earthquake-induced disorders are introduced to the shape of the building. Computing these two selected features shows that they are statistically uncorrelated. Figure 4 is the scattered plot of these two features as computed for all parcels.
D. Fuzzy Inferencing

In order to evaluate all the parcels with respect to each other, the spectral correlation and the edge density difference indices are normalized with respect to unity. The computed correlation values are between the range of [-1, 1] but they are mapped to the range between zero to the unity using the absolute value of the numbers. For the second index, a linear transformation is decided to map the value to the range of [0,1]. The membership functions shown in Figure 5 are devised as to describe the regions that likely represent the tendency of the feature being categorized as Low, Medium and High. Comparing the values for these features across the before and after images and using expert judgments the fuzzy classification rule is devised as summarized in Table 2.

III. Result

It is necessary that a definite assignment takes in effect to classify the parcels (defuzzification). In the fuzzy calculation process, the underlying values corresponding to the Table 2 under features 1 and 2 are compared as the “And” operator. Therefore, the minimum value corresponding to the two features in each row of Table 2 is extracted from the curves shown in Figure 5 and entered in the last column in this table. In the decision step, the maximum assigned value between all “Slight”, “Moderate”, and “Severe” values of the last column in Table 2 is considered for the assessment.

As an example, for the parcel ID: 20816, Table 3 gives three membership values according to three predefined damage levels. The highest membership value classifies the parcel so the parcel damage level is decided as “Slight or None”. The result shown in Figure 6 is the application of the fuzzy rules to the two mentioned features for each parcel in the entire city of Bam. This map delineates between three levels of building damage as “Slight or None”, “Moderate” or “Severe”.

Table 2 – Fuzzy classification rules

<table>
<thead>
<tr>
<th>Feature 1</th>
<th>Feature 2</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Low or Medium</td>
<td>Slight</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Medium</td>
<td>Low</td>
<td>Slight</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>Moderate</td>
</tr>
<tr>
<td>Medium</td>
<td>High</td>
<td>Severe</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Low</td>
<td>Medium or High</td>
<td>Severe</td>
</tr>
</tbody>
</table>

Table 3 – Fuzzy classification rules

<table>
<thead>
<tr>
<th>ID: 20816</th>
<th>Slight or None</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.72</td>
<td>0.28</td>
<td>0.12</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6 - Damage Map from defuzzification
A. Reliability Analysis

In the process of defuzzification, each parcel is assigned to a class according to its highest membership value. It can be stated that the higher difference between the maximum value of the membership with respect to the next important membership value implies the more reliable classification results. Therefore the reliability index is defined as the ratio of the difference of the two consecutive higher membership values to the maximum membership value. This value will be 62% for the example listed in Table 3. The reliability index is calculated for the entire city of Bam as shown in Figure 7 where the great majority of the parcels are classified with more than 75% reliability.

B. Verification with direct visual observation

The results of figure 6 are verified against the results obtained from a direct visual damage classification using the VHR optical data and the EMS98 damage grades presented by Yamazaki et al. [4].

Table 4 compares the results of fuzzy classification with the visual damage interpretation where for complete building collapse, the relative accuracy of 72% is achieved. Since this level of damage is responsible for most of the human loss, the methodology explained in here can be exploited for early phase of disaster management as rescue activities.

IV. CONCLUSION

A parcel-based approach for building damage detection is presented that take advantage of combining the information from the ancillary parcel data with remote sensing VHR optical images. Effective spectral and spatial change detection features are chosen as the basic elements in the fuzzy classification. The fuzzy methodology uses these features and introducing some membership curves, fuzzified categorical memberships are obtained for three levels of “Slight or None”, “Moderate” and “Severe”. A defuzzification procedure is applied and the entire city is classified for the above three damage grades. The reliability of the classification is computed and is high. Also the results were verified against a reported visual damage interpretation and good agreement is achieved for the collapse damage grade.

ACKNOWLEDGMENT

IIIES is acknowledged for supporting the research project # 327-8302. Also the support of the University of Pavia, MCEER, EERI, UCI, IUSS, EUCENTRE is appreciated. VHR optical data was provided by DigitalGlobe. The authors would like to thank EERI and UCI for their purchase of Quickbird imagery. Professor Yamazaki is acknowledged for providing the authors with the visual damage interpretation data for the Bam earthquake.

REFERENCES