

Earthquake Damage Detection Using High-resolution Satellite Images

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Abstract— QuickBird observed the city of Zemmouri, Algeria, before and after the May 21, 2003 Algeria earthquake. Using the pre-event and post-event pan-sharpened images, visual inspection of building damage was carried out by the five authors of this paper individually. A total 1,399 buildings were classified into five damage levels of European Micro-seismic Scale. The results from the different interpreters were reasonably close for collapsed buildings but the difference becomes larger for smaller damage levels. The locations of refugee tents in the two post-event images were also identified. These observations indicate that high-resolution satellite images can provide quite useful information to emergency management after natural disasters.

Keywords—QuickBird; the 2003 Algeria earthquake; building damage; visual inspection; Zemmouri City

I. INTRODUCTION

Recent advancements in remote sensing and its application technologies made it possible to use remotely sensed imagery for assessing vulnerability of urban areas and for capturing damage distribution due to natural disasters [1]. Especially it is important for emergency management and recovery works to capture damage distribution immediately after an earthquake or other disasters.



Figure 1. Pan-sharpened QuickBird image of Zemmouri on May 23, 2003

QuickBird, a high-resolution commercial satellite with the maximum spatial resolution of 0.6 m, launched successfully on October 18, 2001 and it acquires optical images of urban areas, in which individual buildings can be identified. Hence, these images can be used to detect damages of individual buildings and infrastructures after natural disasters. Using the images obtained by QuickBird before and after the 21 May, 2003 Algeria earthquake, this paper presents the results of visual damage detection for Zemmouri City to demonstrate the capability of high-resolution optical satellite images.

II. THE 2003 ALGERIA EARTHQUAKE AND QUICKBIRD IMAGES

A strong earthquake of magnitude 6.8 struck the Mediterranean coast of Algeria on May 21, 2003. The epicenter was located at 36.90N, 3.71E (USGS), offshore of the province of Boumerdes, about 50 km east of the capital city, Algiers. According to the last official report from National Earthquake Engineering Center of Algeria, 2,278 people were killed, more than 10,000 were injured and about 180,000 people were made homeless. Zemmouri City is one of the most heavily damaged areas due to the earthquake.

First, three pan-sharpened images (one pre-event on May 13, 2003, and two post-event images on May 23 and June 13, 2003) were produced (Fig. 1) and they were used in visual inspection of building damage. Figure 2 shows the urbanized



Figure 2. Central part of Zemmouri City on May 23, 2003

area of Zemmouri on May 23, two days after the earthquake, in which many collapsed buildings are observed.

TABLE I. CLASSIFICATION OF DAMAGE TO REINFORCED CONCRETE BUILDINGS (EMS, 1998).

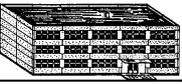
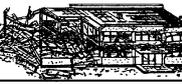
| Damage Pattern | Damage Level |
|---|---|
|  | Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage) |
|  | Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) |
|  | Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) |
|  | Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) |
|  | Grade 5: Destruction (very heavy structural damage) |

TABLE II. COMPARISON OF THE DETECTION RESULTS OF THE FIVE INTERPRETERS

| Damage / Interpreter No. | #1 | #2 | #3 | #4 | #5 | Majority | |
|--------------------------|------------------|------|------|------|------|----------|---|
| Grade 1 or 2 | 923 | 973 | 1168 | 1122 | 1120 | 1128 | |
| Grade 3 | 200 | 107 | 4 | 73 | 65 | 35 | |
| Grade 4 | 96 | 128 | 78 | 56 | 32 | 62 | |
| Grade 5 | 180 | 191 | 149 | 148 | 182 | 174 | |
| Total | 1399 | 1399 | 1399 | 1399 | 1399 | 1399 | |
| Detection time (hours) | Using one image | 2.5 | 4 | 3 | 4 | 2.5 | - |
| | Using two images | 5 | 3.5 | 4.5 | 5 | 2.5 | - |

III. DAMAGE CLASSIFICATION AND DAMAGE DETECTION

Visual inspection of building damage was conducted based on the classification in the European Macroseismic Scale [2], shown in Table I. Using only the post-event (May 23, 2003) image and using both the pre- and post-event images, buildings surrounded by debris (Grade 3), partially collapsed buildings (Grade 4) and totally collapsed buildings (Grade 5) were identified. For the purpose to obtain more confidence in the result of visual detection, five persons (actually the authors of this paper, who are researchers and graduate students in the fields of structural engineering) conducted visual inspection and the differences among their results were investigated.

From the results of individual damage detection, “the majority damage level” was determined. Comparing the number of persons who classified a building as “no damage” (Grade 1 or 2) with that as “damaged” (a total of Grades 3 to 5), if the former is majority, the damage level of the building is determined as “Grade 1 or 2”. If not, the damage level is determined in the next stage, by comparing between the numbers of persons who classified it as Grade 3, 4 or 5. Even

after this procedure, the damage grade of some buildings cannot be determined. If the result by the five persons includes Grade 3 to 5, the damage level is classified as Grade 4. Otherwise the damage level is classified as the severer level.

IV. VISUAL DAMAGE DETECTION OF ZEMMOURI CITY

The detection results of the five interpreters and the majority grade using both the pre- and post-event images are shown in Table II. The numbers of buildings classified to the majority damage levels were 35, 62, and 174 for Grades 3, 4, and 5, respectively, based on the pre- and post- event images. The other 1,128 buildings were classified as Grade 1 or 2 out of a total of 1,399 buildings. The interpreters #1 and #2 tend to judge the damage to severer levels than the others. Consequently, through the first majority decision rule, the interpreters #3, #4 and #5 became the majority in many cases.

The differences of the numbers of classified levels between using only the post-event image and using both the pre- and post-event images are investigated. For Grades 3, 4 and 5, the difference among the interpreters is seen to be larger. Especially it may be difficult to identify buildings as Grade 3 by using only a post-event image.

The average number of interpreters who classify the damage level same as the majority level for Grade 5 is larger than those for Grades 3 and 4. The identification of “collapse (Grade 5)” buildings does not vary much although it is necessary to evaluate its accuracy based on ground truth data. On the other hand, it is difficult to reach a consensus for identifications of “moderate damage (Grade 3)” or “partially collapsed (Grade 4)” cases.

The average numbers who reached the same damage grades based on the two images inspection are larger than those based on the one image inspection. Hence the detection results based on the two images can be said more stable than those based on the one image.

V. COMPARISON WITH GROUND TRUTH IMAGES AND DISCUSSION

Figure 3 shows comparison between the satellite image and the on-site video pictures. In the satellite image, a circle symbol means “Grade 1 or 2”, a triangle symbol “Grade 3”, a diamond symbol “Grade 4”, and a star symbol “Grade 5”, respectively. The lower pictures show damaged/collapsed tall buildings (A) and a damaged low-rise house (B), which are examples that the detection results using satellite images were verified by ground photographs.

A total of 1,399 buildings in the central part of Zemmouri City were classified based on their damage grades as shown in Figure 4. The damage ratios of buildings in each city block (a total 15 blocks) were calculated. Figure 5 shows the damage ratio of Grade 5 for each city block. It is seen that the heavy damage zone is concentrated in the central part of the urban area. The distribution of tents can clearly be observed in QuickBird images of Zemmouri. The locations of tents in the two post-event images were plotted in Fig. 6.

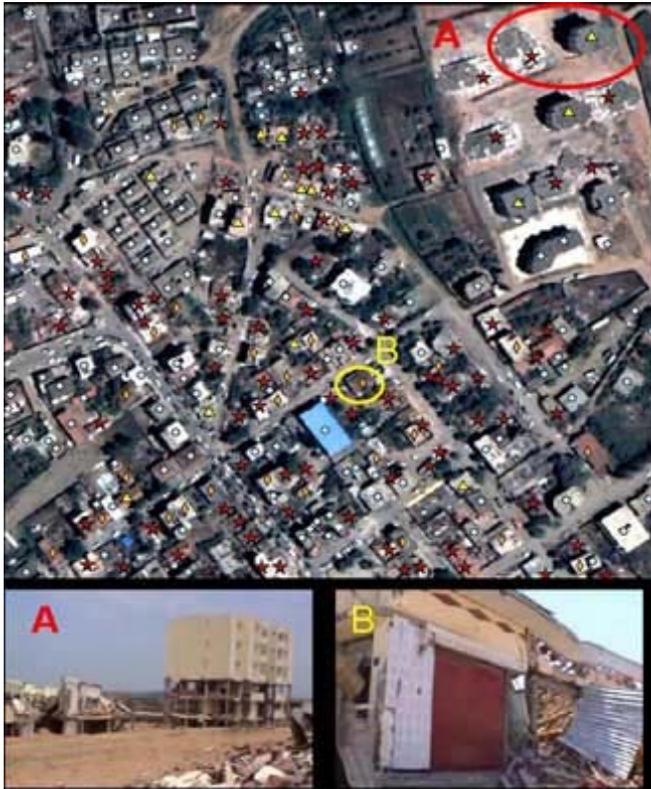


Figure 3. Comparison between the satellite images and on-site video (by courtesy of National Earthquake Engineering Center of Algeria).

The damage map in Zemmouri evaluated by the United States Government is available on Internet (UN-OCHA [3]). Figure 7 compares the damage map in Zemmouri evaluated by the United States Government and the result of this study. We contacted UN-OCHA about the data source, but only reply we received is “It used a variety of classified and unclassified aerial and satellite remote sensing images.” Although the map by US Government is very close to our interpretation, there is possibility that they also used QuickBird images as a part of data source.

Among the five interpreters, the interpreter #1 also conducted visual detection for Boumerdes City [4] using QuickBird images. It should be pointed out that the damage ratio of buildings was different by the one-image and two-image interpretations. For Boumerdes, the difference in the ratios is 17.1% (of which the buildings identified as “Unclear” based on one image was 15.6%) and for Zemmouri 23.2% (of which 17.5% unclear). Hence, it is more difficult to classify damaged buildings in the image of Zemmouri than that of Boumerdes. The satellite images of Zemmouri indicate that there are more low-rise buildings placed close together. This fact explains the difference of difficulty in image interpretation.

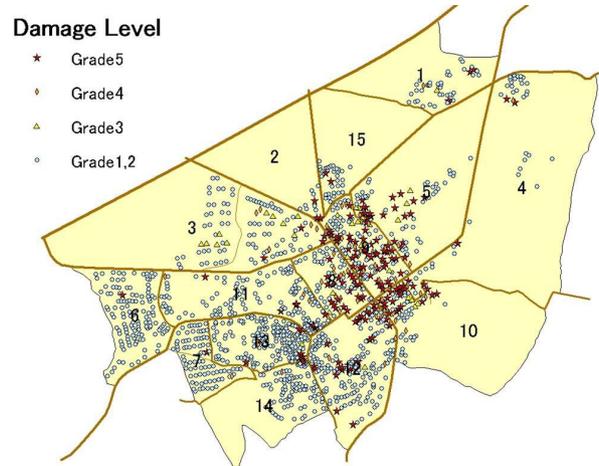


Figure 4. 1,399 buildings classified based on their damage grades

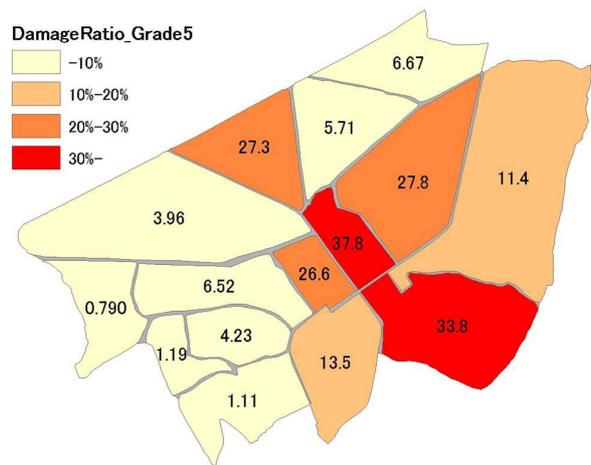


Figure 5. Ratio of Grade 5 buildings in each city block

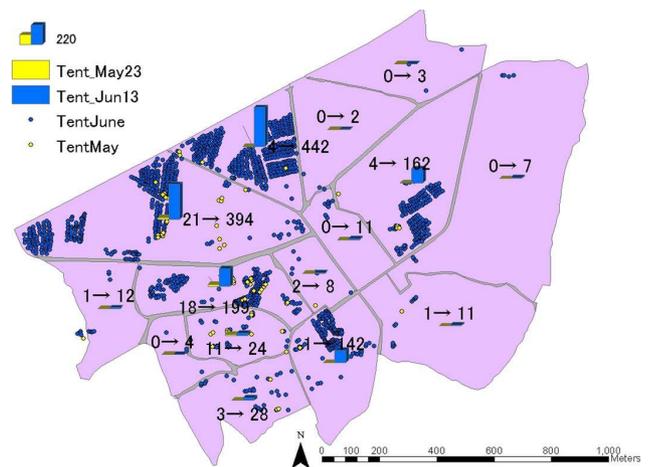
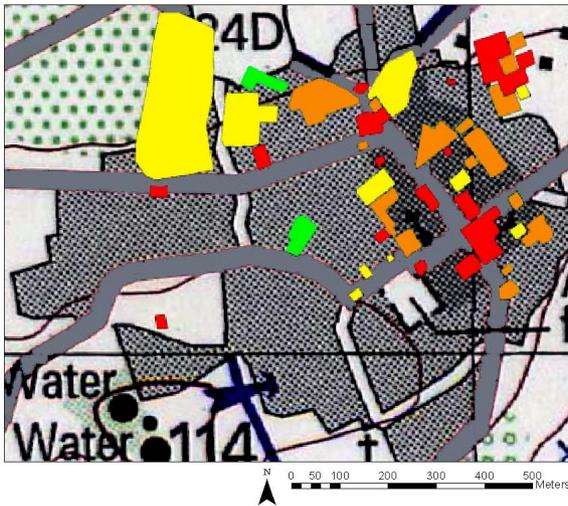
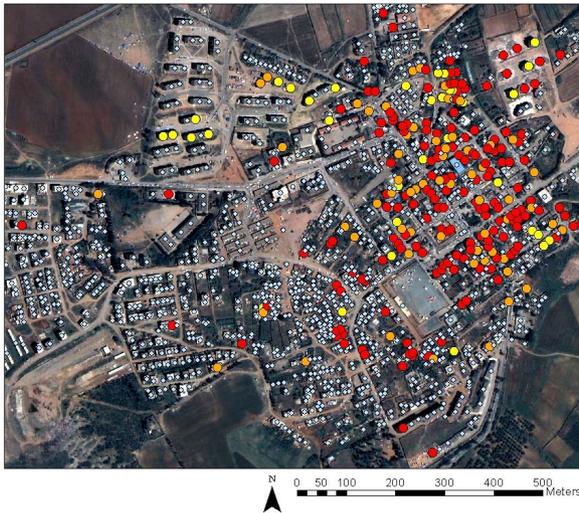


Figure 6. Location of tents in the two post-event images

A future research is suggested on the relationship between the damage ratio and building type, the accuracy of interpretation, and the application of automated damage detection [5].



(a) Damage map for Zemmouri evaluated by the United States Government (UN-OCHA, 2003)



(b) Visual damage detection by this study

Figure 7. Comparison of damage map made by US Government and this study

VI. CONCLUSIONS

Using the high-resolution satellite images of Zemmouri, Algeria, acquired by QuickBird before and after the 21 May, 2003 Algeria earthquake, visual interpretation of building damage was conducted by five interpreters. Using only the post-event pan-sharpened image, buildings surrounded by debris (Grade 3), partially collapsed buildings (Grade 4), and totally collapsed buildings (Grade 5) were identified. Some buildings were difficult to judge their damage levels, and thus, the pre-event image was also employed as a reference to judge the damage levels. A total of 1,399 buildings were classified and the locations of refugee tents in the two post-event images were also detected. The results from the different interpreters

were reasonably close for collapsed buildings, but the difference among the interpreters becomes larger for smaller damage levels.

ACKNOWLEDGMENT

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