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AUTOMATED DAMAGE DETECTION OF BUILDINGS FROM HIGH-RESOLUTION SATELLITE IMAGES

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SUMMARY

A strong earthquake of magnitude 6.8 struck the Mediterranean coast of Algeria on 21 May 2003 and the city of Zemmouri in Boumerdes wilaya was most heavily damaged. QuickBird satellite observed the Zemmouri area on 23 May 2003. By image sharpening, buildings, cars and even debris can clearly be identified in a natural colour image. Preliminarily, the present authors performed visual damage inspection comparing the post-event image with an image acquired before the earthquake. As a result, totally collapsed buildings, partially collapsed buildings, and buildings surrounded by debris were visually identified. Additionally, debris surrounding damaged buildings was also extracted. Although these observations indicate that high-resolution satellite images would be able to provide quite useful information to emergency management after natural disasters, it can also be said that the visual damage interpretation is time-consuming. For practical purposes, it must be necessary to complete damage detection as quick as possible after the occurrence of disasters in order to make use of the detection result in emergency management. Hence, an automated damage detection method, in which debris is identified, is required to be developed. In this study object-based image segmentation and classification technique as well as pixel-based technique have been applied. This technique would make it possible to consider not only the spectral characteristics of objects but also the spatial relationship between objects that consist of homogenous pixels. For the purpose of investigating their effectiveness on identifying debris, the accuracy of the detection result has been assessed and compared with that of the pixel-based damage detection result.

1. INTRODUCTION

In the stage of emergency management after the occurrence of natural disasters, a quick response including rapid decision-making and information-gathering seems to be crucial as was shown through the experience of Hurricane Katrina in the United States [White House, 2006]. Recent advancements in remote sensing and its application technologies have made it possible to use remotely sensed imageries for capturing damage distribution due to natural disasters. Especially it is important to capture extensive damage distribution immediately after earthquakes or other disasters. For example, when the Indian Ocean Tsunami hit Thailand, a large number of remotely sensed imageries acquired before and after the tsunami were very useful for rescue and rehabilitation actions [Vibulsreth *et al*., 2005]. Therefore, remote sensing data is thought to perform an important role in collecting information of damage in broad areas.

Since remote sensing data observed by various platforms have both advantages and disadvantages in immediacy, periodicity and resolution, it is necessary to consider the characteristics of each platform and sensor and the quality of data when they are used. In order to examine the applicability of remote sensing technologies to emergency management after earthquakes, visual damage detection was performed using aerial photographs [Ogawa and Yamazaki, 2000]. These kinds of images can identify individual buildings but they cannot cover a wide area with one acquisition time. On the other hand, satellite images have an advantage to observe a large

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area in a short time interval, that is several days. In addition, it was demonstrated that high-resolution satellite images could be applied to detecting building damage [Yamazaki *et al*., 2004].

The result of visual damage detection provides useful information of reasonable accuracy for emergency management in spite of the fact damage levels judged from vertical images are estimated relatively lower than actual damage levels [Yano et al., 2004]. However, it can be said that the visual damage interpretation of a large number of buildings is time-consuming. Hence, automated damage detection is required to be developed. In fact, Mitomi et al. (2002) developed the method of detecting debris automatically by using the edge information of aerial images. However, in this kind of traditional pixel-based methodology it appears to be difficult to make use of spatial concepts effectively [Blaschke and Strobl, 2001]. Additionally, it is said that the high-resolution imageries increase spectral variability within each field and therefore may decrease the classification or recognition accuracy of methods on pixel basis and then object-based approach has been suggested as an advanced solution for image analysis [Huiping *et al*., 2003]. It has also been applied to the earthquake case by carrying out the object-based change detection and comparing the result of pixel-based method [Bitelli *et al*., 2004].

The aim of this paper is to conduct both pixel-based and object-based damage extraction for the urban area of Zemmouri using only one image obtained by QuickBird, a high-resolution satellite launched on 18 October 2001, two days after the 2003 Algeria earthquake and compare the accuracies of these two results referring to the result of visual detection of debris [Yamazaki *et al*., 2004] so as to evaluate the capability of object-based methodology.

2. THE 2003 ALGERIA EARTHQUAKE AND QUICKBIRD IMAGES

A strong earthquake of magnitude 6.8 struck the Mediterranean coast of Algeria on 21 May 2003. The epicenter was located at 36.90N, 3.71E (USGS), offshore of the wilaya of Boumerdes, about 50 km east of the capital city, Algiers (Fig. 1(a)). 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.

QuickBird satellite observed the areas of Zemmouri City in the wilaya of Boumerdes. The images of Zemmouri City were obtained 8 days before (13 May 2003) and two days after (23 May 2003) the event. In order to observe target areas in a short time interval, QuickBird can change the view angle of its sensors. Thus these two images have different off nadir view angles: 8.7 and 24.4 degrees. Hence it is by no means easy to superpose these images exactly, especially in the areas where tall buildings are located, and to perform automated change detection. This is the reason why not change detection but detection from one post-event image has been used in this study.

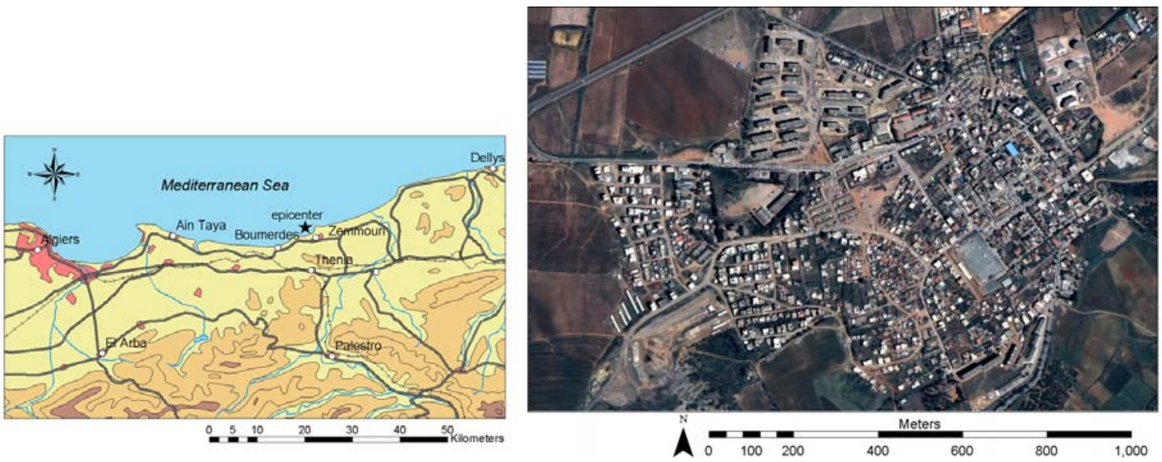


Figure 1: (a) Epicenter and damaged cities in the north of Algeria and (b) pan-sharpened natural colour QuickBird image of Zemmouri City acquired on 23 May 2003

First of all, radiometric conversion and atmospheric correction needs carrying out because the final goal of this study is to develop an image-independent detection method and also some band ratio operations such as vegetation indices are used. After converting observed digital number into at-satellite radiance, $L_{sat\lambda}$ [DigitalGlobe, 2003], the DOS (Dark-object subtraction) model [Lu *et al.*, 2002] was applied so that $L_{sat\lambda}$ was converted into surface reflectance, $\rho_{p\lambda}$, following the Eq. (1).

$$\rho_{p\lambda} = \frac{\pi d^2 (L_{sat\lambda} - L_{s\lambda})}{E_{sun\lambda} \cos\theta_z} \tag{1}$$

where $L_{s\lambda}$ is the path radiance, E_{sun} is the exo-atmospheric solar irradiance, d is the distance between Earth and the sun, and θ_z is the sun zenith angle. Then, pan-sharpened images were produced through combining panchromatic images of 0.6 m resolution and multi-spectral images of 2.4 m resolution, as shown in Fig. 1(b). By this image enhancement, buildings, cars and debris can clearly be identified. A pre-event image and a post-event pan-sharpened image were produced and they were used in visual damage inspection. As well as that, the post-event image was used in automated damage detection.

3. DAMAGE DETECTION OF ZEMMOURI CITY

There were three steps in this study. Firstly, 1) visual detection of debris from pre- and post-event images was performed, preliminarily. Secondly, damage areas were automatically extracted using both 2) a pixel-based method and 3) an object-based method. Finally, based on the visual detection result, the accuracies of the two automated detection methodologies were evaluated, which is mentioned in the next section. The flowchart of all the operations beginning with the acquisition of images is shown in Fig. 2, and the study area in this paper is shown in Fig. 3.

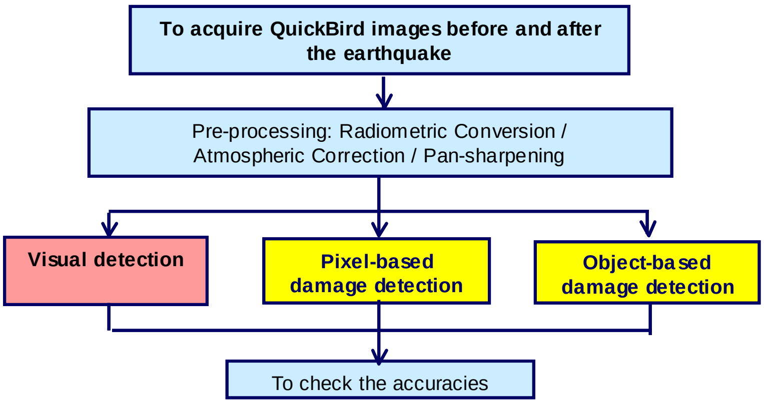


Figure 2: Flowchart of all the operations

Figure 3: QuickBird image of the study area in Zemmouri City

3.1 Visual Detection of Debris

The visual inspection of building damage in Zemmouri City was conducted based on the classification in the European Macroseicmic Scale [European Seismological Commission, 1998] shown in Table. 1. 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 the visual detection, five persons, who are researchers and graduate students in the fields of structural engineering, conducted visual inspection and majority damage levels were determined [Yamazaki *et al*., 2004]. The detection result of the majority grade is shown in Fig. 4(a). As is mentioned above, this result would have an acceptable accuracy and be really useful in the damage analysis of disasters although, ideally, it is necessary to evaluate the accuracy of the detection result based on ground truth data.

Next, as is shown in Fig. 4(b), debris due to the destruction of buildings was identified and extracted focusing on buildings classified as damaged in the visual inspection. Out of 262,114 pixels in the 512x512 image, 23,493 pixels were judged as the areas of debris. These could be considered to be reliable truth data to evaluate the accuracies of automated damage detection techniques. It should also be mentioned that it took a half to an hour to detect debris areas this time.

Table 1: Classification of damage to buildings

Level	Description
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)

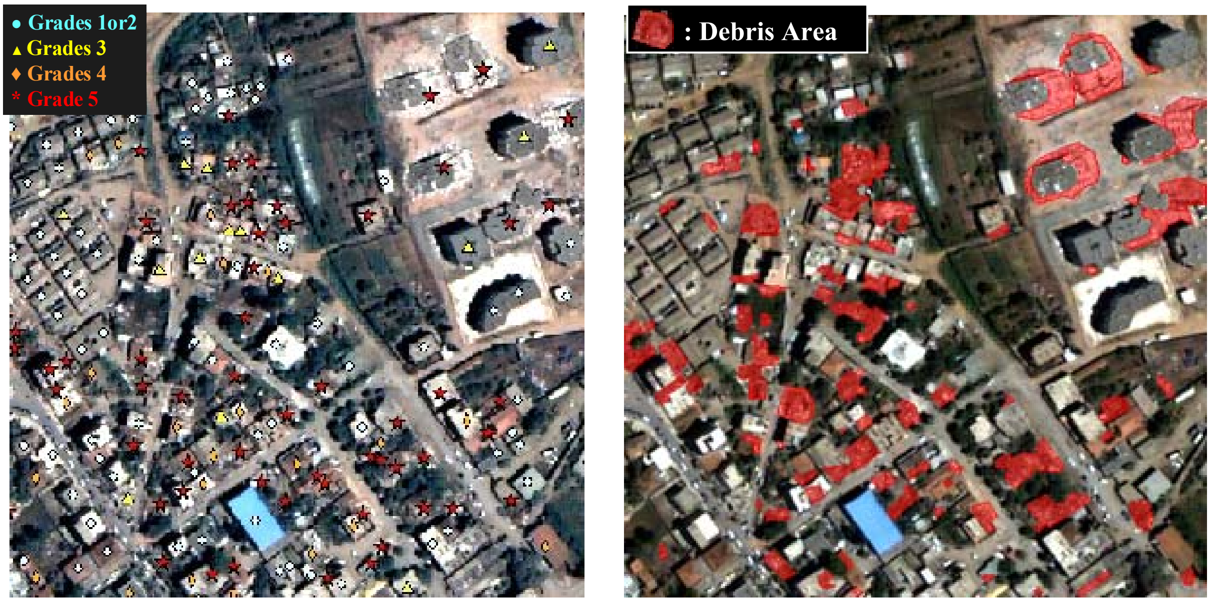


Figure 4: (a) Result of visual building damage detection and (b) distribution of debris visually detected

3.2 Pixel-based Approach

In order to reduce operation time of damage detection, an automated detection method by image processing should be proposed. At first, a traditional pixel-based approach was tested. In this study 8-bit data of blue, green, red, near infrared, and brightness were simply employed as indices of land cover classification aimed at detecting the debris class because it is just intended to compare characteristics between the pixel-based method and the object-based method. As for a classification type, the maximum likelihood (ML) classification, which is the most common of supervised classification methods, was selected.

Before performing ML classification, classes were set as follows: gray-roof building, white-roof building, red-roof building, blue-roof building, car, shadow, road, soil, vegetation, and debris. Then, samples for all classes were selected from the post-event image. Finally, the image was classified into the classes mentioned above and only the class of debris was extracted. Fig. 5(a) shows debris areas classified by the pixel-based approach and those visually detected.

As a result, it seems that debris that has been detected is scattered about in the whole image. Additionally, this result indicates that the area classified as debris in the visual detection is not so large and that some errors are seen on the roofs of buildings. The accuracy is discussed and compared with the result of object-based classification in the next section later.

3.3 Object-based Approach

Classification based on segmented objects was also carried out. The basic operations of object-based classification conducted in this study using the software, eCognition [Definiens Imaging GmbH, 2000], are as follows.

First, the post-event image was segmented into objects. As a result of segmentation, pixels that were judged to be homogeneous were merged into one object and then converted to a polygon. In this process, heterogeneity of spectra, h_{colour}, shown in Eq. (2) was calculated and compared with the threshold called the scale factor. Data layers of blue, green, red, near-infrared, and brightness were used in the segmentation.

$$h_{colour} = \sum_{layer\_c} (n_{merge} \cdot \sigma_c^{merge} - (n_{obj1} \cdot \sigma_c^{obj1} + n_{obj2} \cdot \sigma_c^{obj2})) \quad (2)$$

where n is the object size and σ is the standard deviation. Because it is difficult to determine automatically suitable scale factors for proper segmentation, the technique proposed by Usuda *et al*. (2005) was adopted. While increasing the scale factor by seven in each step, the growth of each object was supposed to stop when the object size did not grow larger for the first time despite of the increase of the scale factor. Consequently, objects that have small variances over a relatively large area, like roads and vegetation, were segmented coarsely and, on the other hand, those like buildings and cars, were finely. This way seems to avoid merging excessive pixels but to cause smaller objects than those in the real world. However, this is definitely better than the reverse in order to classify the real objects properly.

Second, samples of classes that consisted of gray-roof, white-roof, red-roof, and blue-roof buildings, car, shadow, road, soil, vegetation, and debris were selected from the same areas as those used in the pixel-based classification. Using the sample objects' mean values of blue, green, red, and near-infrared band values, and brightness data as indices, the nearest neighbor classification, which is one of the supervised classification techniques, was conducted. After that, the objects classified as the debris class were extracted and shown in Fig.5(b).

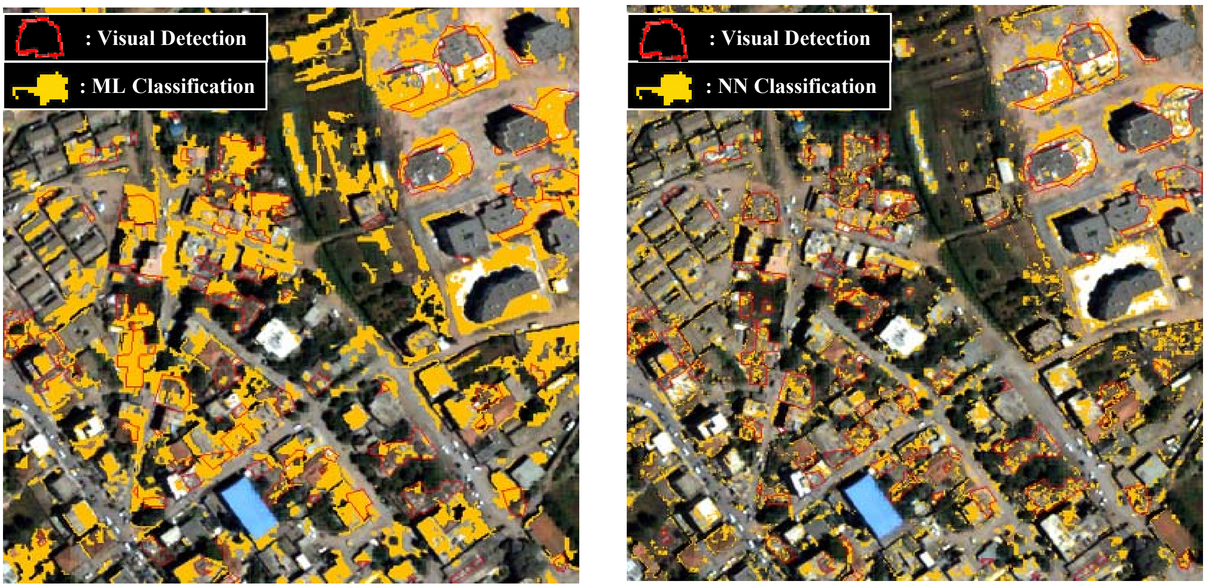


Figure 5: (a) Debris detected by pixel-based approach and (b) debris detected by object-based approach

Considering the result of the object-based classification, larger areas visually detected as debris have been identified as debris in the object-based damage detection than the pixel-based detection. However, it seems that more errors exist in the areas of white buildings and vegetation. Since merging pixels has removed the variance of spectral data among neighbouring pixels, it can be seen that dotted errors and voids have disappeared. In other words, this approach could realize that an object that spreads to some extent is certainly identified as one homogenous area despite the minute fluctuations of pixel data within the object.

4. COMPARISON BETWEEN "PIXEL" AND "OBJECT"

Errors of the automated damage detection results were calculated based on the result of the visual damage detection, and then the accuracies of both approaches were evaluated and compared. Table 2 shows "commission error", "omission error", "producer accuracy", and "user accuracy", whose definitions are described in the table.

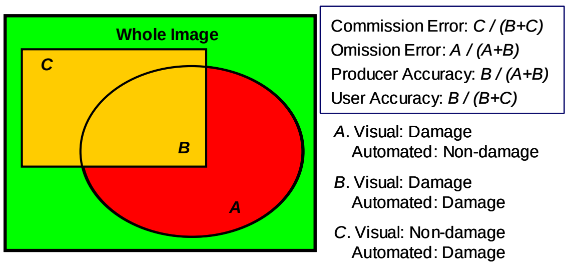
According to Table 2, it can be said that the pixel-based approach caused less commission error than the object-based approach. Therefore, it is likely that fewer pixels will be extracted wrongly from the no-damage area in the pixel-based approach. In contrast, the object-based approach caused less omission error. Therefore, it is likely that more pixels will be extracted correctly from the damage area in the object-based approach.

As for the accuracies, the pixel-based approach has achieved higher user accuracy, while the object-based approach higher producer accuracy. This result indicates that both have advantages and disadvantages. However, it could be concluded as follows. The accuracy of the pixel-based method would not be high enough. On the other hand, the object-based method would be able to detect a half of the actual damaged area, but the user accuracy of this method is so low that it might still be difficult to regard some extracted areas as damaged areas.

Since it has been demonstrated that the object-based approach is effective on classification and therefore the detection of debris, this method is worth improving in the future study. Information of edge and shape, which is not as dependent on images of each case as colour information, is planned to be employed as indices. Especially, shape information is a unique characteristic of the object-based approach. Hence, appropriate use of that information must be considered in order to increase the accuracy of detection.

Table 2: Errors and accuracies of automated damage detection

	Commission Error	Omission Error	Producer Accuracy	User Accuracy
Pixel-based	76.8%	67.93%	32.07%	23.20%
Object-based	80.36%	50.02%	49.98%	19.64%



5. CONCLUSIONS

For the purpose of developing an automated damage detection method that has reasonable accuracy and necessary information and can complete all operations within several hours, simple automated detection methods have been performed. There are a traditional pixel-based approach and an object-based approach, which is thought to be an advanced solution for the disadvantages of the pixel-based approach. In both cases, using the information of colour and brightness as indices, supervised classification has been conducted in order to extract the debris class. Regarding the truth data, the result of visual detection has been used because its accuracy is considered to be reasonably high.

Comparison between the pixel-based case and the object-based case, it is demonstrated that the pixel-based approach has achieved higher user accuracy (23.2%), while the object-based approach higher producer accuracy (49.98%). In addition to this, the accuracy of the pixel-based method would not be high enough for a practical application. On the other hand, the object-based method could detect about 50% of the actual damaged area, but the user accuracy of this method might still be low.

In order to develop the application to automatically detect debris, it is necessary to improve the accuracy of the method by determining appropriate indices like edge and shape information in the future work. Moreover, it is also essential to obtain ground truth data of building damage in the area of Zemmouri. Otherwise, it will be difficult to judge if the method can be used or not, in practice. Lastly, these should be considered as well: "How accurate the method needs to be ?" and "What kind of information needs to be detected".

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