Context-based detection of post-disaster damaged buildings in urban areas from satellite images

T. Thuy Vu, Fumio Yamazaki
Department of Urban Environment Systems
Faculty of Engineering, Chiba University
Chiba, Japan
thuyvu@as.tu.chiba-u.ac.jp, yamazaki@tu.chiba-u.ac.jp

Masashi Matsuoka
Earthquake Disaster Mitigation Research Center
NIED
Kobe, Japan
matsuoka@edm.bosai.go.jp

Abstract— **This paper presents a new context-based damage detection approach using high-resolution optical satellite images. To exploit rich information represented in such high-resolution images, the proposed approach is designed to learn the image context based on the combination of the edge-based textures, the multi-spectral gray tone, and the spatial relationship formulated through a morphological scale-space. While edge-based textures infer the debris of damaged buildings, multi-spectral gray tone and spatial relationship provide the cues to extract the retained buildings after a catastrophe. It is demonstrated through processing a QuickBird image acquired over the damage areas of Bam city, Iran, which were severely hit by the earthquake on 26 December 2003.**

I. INTRODUCTION

Remotely sensed data acquired by various satellite sensors are the quickest information about an occurring catastrophe. Using those data in post-disaster response is very useful, especially for the hard-hit and difficult-to-access areas. In regards to earthquake disaster, many researches and implementations have been carried out following the recent earthquakes such as the 1995 Kobe, Japan earthquake [1], the 1999 Kocaeli, Turkey earthquake [2,3], the 2001 Gujarat, India earthquake [4,5], the 2003 Bam, Iran earthquake [6,7], the 2006 Central Java earthquake [8,9]. The availability of higher resolution images such as QuickBird and Ikonos these days allows the interpretation of damage status of each building block or even each individual building rather than overall damage distribution and damage extent. However, those high-resolution satellite images also introduce higher internal variability and noise within each land-cover class. Therefore, the pixel-based algorithms fail in handling them. A pixel should be understood in the context of its surroundings.

At a higher level of processing, texture-based algorithms analyze different kinds of relationship among the neighbors of each pixel such as variance, homogeneity, entropy, and angular second moment. The combination of the edge-based textures including the edge variance, the edge direction, the entropy and the second moments has been successfully employed in detection of damage areas, debris indeed, caused by an earthquake [4,6]. Observing the changes of edge information to detect the damages is a common approach. To deal with high-resolution satellite image and target on damage status of each building feature, the object-based approaches have been used [9-10] [11-13]. Either texture-based or object-based approach, they are suffered by various drawbacks. Texture-based algorithms are simpler processing but fewer contexts involved. The building itself is not concerned in the processing. As a result, only totally collapsed areas can be detected. Object-based ones, on another hand, are more complicated. It is very difficult to find an optimal parameter set to reconstruct the objects, e.g. scale factor, scale parameters and the weights [9-10] or object sizes [11-13]. It is meaningless to apply object-based approach to detect the debris. In addition, the object-based approaches successfully detect the retained buildings but not the damaged ones. Additional pre-disaster information is needed. Both the cues detected from texture-based and object-based approaches represent the context of the scenes. Using all of them, an image scene can be more understandable and hence, it is easier to detect the damage information.

We propose a context-based approach, which simulates the human perception, as follow. We exploit two of our previous developed algorithms in reconstructing the context here. These are the edge textures [6] and object-based processing [12]. First, the debris and the retained buildings are picked up through analyzing the textures and integrated spectral with morphological information, respectively. Second, two detected results are crosschecked by a spatial analysis. Consequently, the exact boundaries of the debris areas are detected as well as the damage status of the retained buildings are identified. The QuickBird image acquired over Bam city, Iran after the earthquake on December 26, 2003 are used for demonstration. Section 2 of this paper describes the proposed approach. Its testing result on Bam data is presented Section 3 and followed by the summary and recommendation for further development (Sections 4).

II. METHODOLOGY

When looking at a satellite image to detect the damaged buildings to perform an visual detection, an operator judges the damage situation based on the areas of debris and the retained buildings. Let S is area occupied by the buildings just before the catastrophe. It means that the changes by other causes such as man-made changes are excluded. Approximately,

$$S = D + R + e \quad (1)$$

where D is the debris area, R is the area occupied the retained buildings and e is the small area occupied by the scattered debris.

Our previous research [6] concluded that the combination of the edge variance (*Ev*), the edge direction (*Ed*), the angular second moment (*Ta*) and the entropy (*Te*) of the edge intensity could be used to detect the debris areas. It is noted that the edges are detected by applying the Prewitt operator. The key is that the debris areas show a distinct edge-based textural behavior in comparison with others excluded the vegetated areas. Thus, the vegetated areas should be removed prior to the texture analysis. It is employed here to provide the first cue for detection of D and e. The retained buildings (R) each of which is obviously formed as an object are detected through an object-based image analysis method. Here we employed and further developed our previous proposed approach [11-12]. Its implementation in the context-based approach is described next.

First, the morphological scale-space is formed separately for each multi-spectral band. There are 4 bands for an Ikonos or QuickBird image. The scale-space is generated based on the area morphological theory introduced by Vincent [14]. The size range of the concerned objects is the only one parameter required. Second, K-mean clustering is carried out to group the pixels into the clusters of a defined number of classes. Based on morphological scale-space, the spatial relationship is taken into account in this clustering. The spectral id is then assigned for every cluster. The cross-correlation analysis is then performed to match the spectral ids across the scale-space. Third, the father-child relationship of the clusters across the scale-space is generated. A cluster (A) on a scale is defined as a child of a cluster (B) on the next coarser scale if it satisfies the following conditions

- A falls into B
- A and B have the same spectral id.

The cluster C, for example, is not a child of B. When a cluster has no father on the next coarser scale like C, it is on its "*root*" scale and can be extracted. The reconstruction of the father-child relationship concerns only the spectral ids related to the building features. An extracted object has three important attributes including its ID, its spectral ID and its scale. Additionally, there are the object area, the object starting point and the object center point.

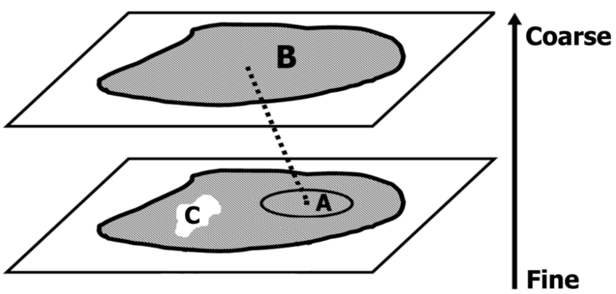

Figure 1. Illustration of the father-child relationship across the scale-space

TABLE I. DAMAGE SCALES BASED ON THE RATIO BETWEEN THE OVERLAPPING AREA IN A BUILDING OVER ITS TOTAL AREA.

Damage scale	Ratio
None	*< 25 %*
Light	*25% - 50%*
Moderate	*> 50%*

The overlap between the detected debris areas and the areas of the retained building objects implies the damage degrees of the buildings. For each retained building, larger overlapping area with the debris area means more debris exists in the building's neighbors. Hence, this building is possibly heavier damaged. We propose the classification of the damage degrees into 3 scales as shown in Table 1. Alternatively, the overlapping areas can be masked out from the detected debris area to precisely form the boundaries of the debris areas. The crosscheck between two results can assist the mitigation of the commission and the omission errors. Consequently, the detected results are the areas of the collapsed buildings and the database of the retained buildings storing their damage degrees.

III. TESTING RESULTS

The QuickBird image acquired on January 04, 2003 was used to demonstrate the performance of the proposed approach. A small test area, about 512 pixels x 512 pixels was selected as depicted in Fig. 2. The center of the scene is at 632103.60m East, 3220900.20m North on the UTM Zone 40 map projection. The biggest retained building approximately equaled 2000 pixels and the smallest one was about 50 pixels. The sizes of buildings in an urban area are normally diverse and unknown in a scene after a catastrophe. We chose 50, 100, 200, 500, 1000 and 2000 pixels as the scale parameters to generate the scale-space. The false-color-composite (FCC) images of the test area on three consecutive scales are illustrated in Fig. 3. It is obvious that the small details disappear gradually when moving to the coarser scales.

Figure 2. False-color-composite (FCC) QuickBird image of the test area.

The unsupervised clustering K-mean was carried out on each scale to group the clusters into 11 classes, i.e. the spectral classes were given the spectral id from 1 to 11 (Fig. 4). It showed that the spectral id number 11 representing most the building features. The spectral property of the building roof was quite uniform. After being linked across the scale-space and extracted, the retained buildings were shown Fig. 5b. In Fig. 5b, the extracted buildings are coded in color based on their ID, one of their attributes, and dark blue as background. The texture-based processing detected the debris areas as shown as the white areas in Fig. 5c.

In object-based extracted results, there were a few commission errors caused by the parts of the roads and open spaces, which have similar spectral information and comparable sizes with the buildings. Also, there were 2 missing building blocks. Their surroundings have very similar spectral property so that they merged with the surroundings into the very large objects and were eliminated in the extraction. In the extracted scene, there existed many small remnants of the collapsed buildings.

The lack of detected results around the scene boundary is the limitation in the texture-based processing. That was caused by the local window operators. The scaling issue was not concerned in the texture processing. Following our previous work [6], we used 7x7 operators in edge detection and texture analysis. The 31x31 local density filter was then applied to remove the small detected areas, which were supposed to be noise. Thus, it could not correctly handle all buildings of diverse sizes. As the scale-space processing produced a good results in terms of accommodating the diverse sizes, the texture processing intergrated in this scale-space might produce better result. Anyway, Fig. 5c presents an acceptable result by texture-based processing.

The spatial analysis was subsequently carried out to crosscheck two results. Because the object-based processing prodived the objects, not simply an image comprising pixels, the spatial analysis here could perform in either raster or vector format. The final result is represented in Fig. 6 with the original FCC image as the background. The result shows good agreement with visual detection of the damage except a few errors aforementioned. A perspective view (Fig. 7) presents the results in a better way. To extrude the buildings over the terrain, we assumed a uniform 3-m height for all buildings.

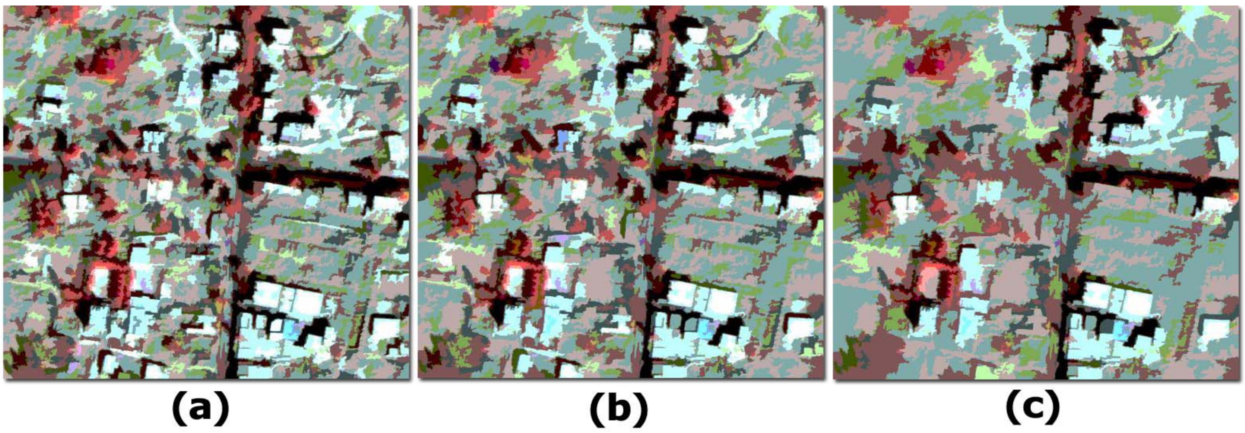

Figure 3. Illustration of the FCC image on three scales 100 (a), 200 (b) and 500 (c) pixels.

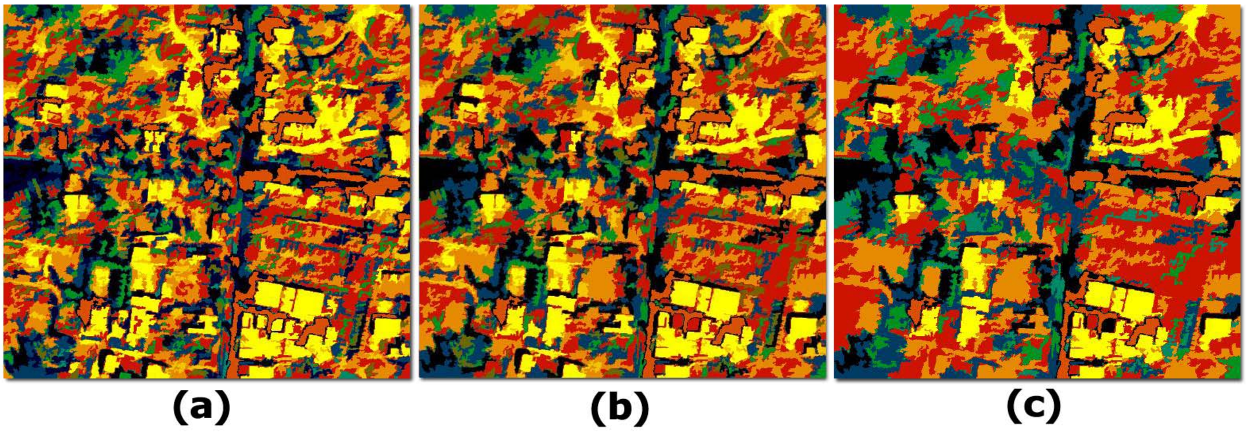

Figure 4. Illustration of the Kmean clustering results on three scales 100 (a), 200 (b) and 500 (c) pixels.

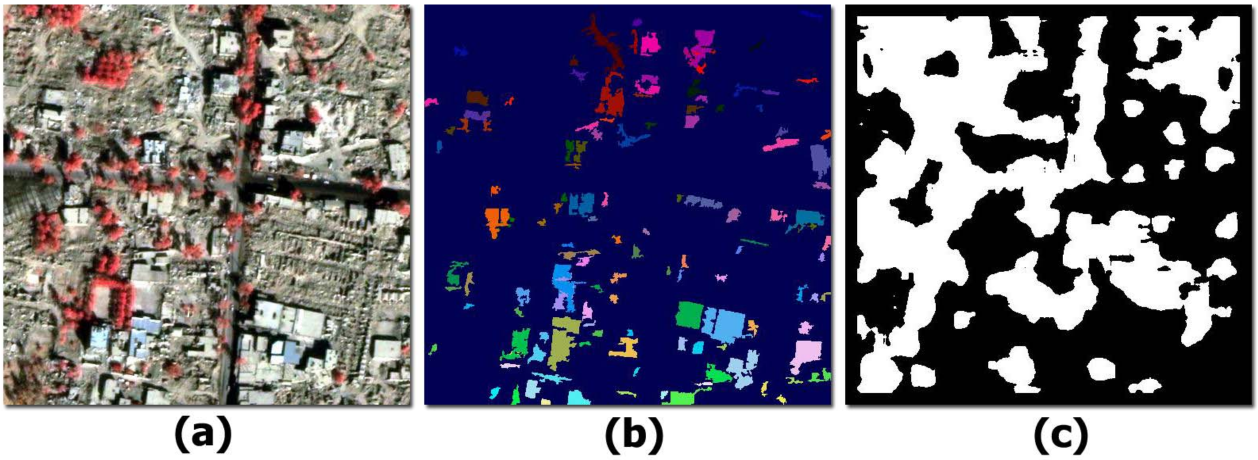

Figure 5. (a) The original FCC image, (b) the extracted retained buildings and (c) the detected debris area

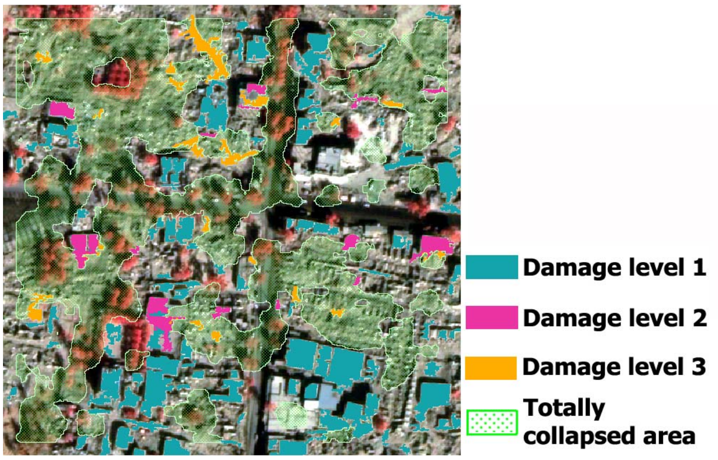

Figure 6. The final detected results with the original FCC image as the background.

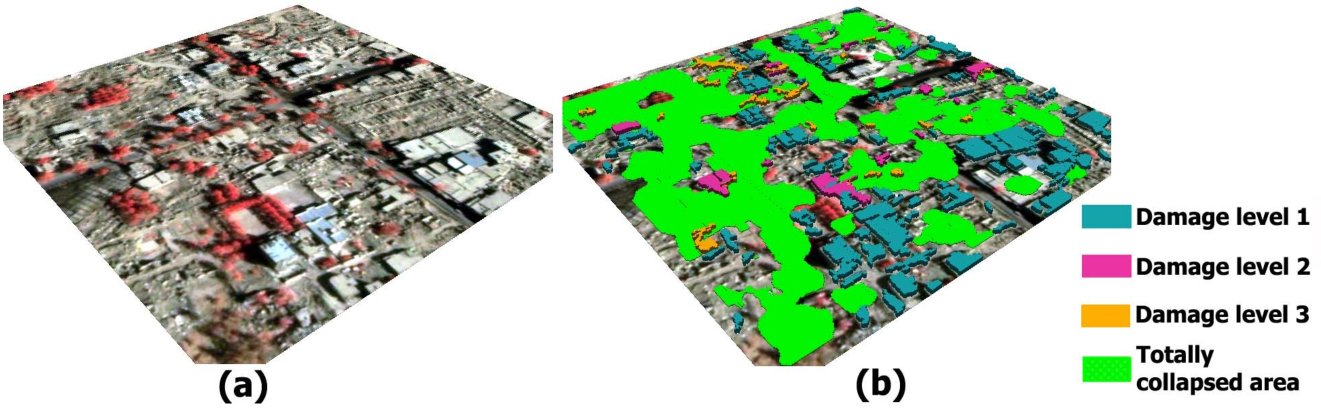

Figure 7. Perspective view of (a) the original FCC image and (b) it with overlain detected results

IV. CONCLUSION

A new context-based detection approach focusing on post-earthquake damaged buildings is proposed. Three important cues contained in a high-resolution satellite image, which are edge-based textures, multi-spectral gray level and morphological-based spatial relationship, are used to describe the context. The demonstration using the data of the 2003 Bam earthquake showed a promising result. Probably, the processing could be improved by integrating texture processing into the scale-space. Especially, vegetated areas can be removed using the detected vegetation objects produced by scale-space processing. It will be the main concern in the next development. It is also recommended to test the proposed approach in an area where the spectral information of the building roofs is more diverse.

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