AUTOMATED DAMAGE DETECTION AND VISUALIZATION USING HIGH-RESOLUTION SATELLITE DATA FOR POST-DISASTER ASSESSMENT

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SUMMARY

The focus of this study is to thoroughly exploit the capability of very high-resolution (VHR) satellite imagery such as IKONOS and QuickBird for disaster mitigation. An efficient automated methodology that detects damage is implemented to derive the rich information available from VHR satellite imagery. Consequently, the detected results and the VHR satellite imagery are attractively presented through a fly-over animation and visualization. The aim is to assist the field-based damage estimation and to strengthen public awareness. The available IKONOS and QuickBird data captured after the Bam, Iran earthquake in December, 2003 was employed to demonstrate the competence of our automated detection algorithm and fly-over animation/visualization. Our results are consistent with the field-based damage detected results.

INTRODUCTION

For decades, remote sensing techniques have been important in grasping damage information caused by earthquakes. Medium resolution satellite data like SPOT, Landsat [1, 2] or ERS [3] is mainly used to identify the extent of the damage. Damaged buildings can be detected using aerial photographs [4]. Recently, very high-resolution (VHR) imagery from commercial satellites such as IKONOS and QuickBird, which can be rapidly acquired, is becoming more powerful and is providing information on natural and/or man-made disasters in the early stages. Both visual interpretation and automated analysis are currently used to detect damaged buildings, but the latter has yet to be reliably implemented. The conventional method for detecting damage caused by an earthquake is to compare pre- and post-event images. This approach has also been developed for VHR data. For example, a new overlay method between pre- and post-event images was based on artificial neural networks [5]. However, it is unrealistic to obtain images of the stricken areas before a disaster, and archived data with clear and suitable images is limited. Therefore, we have been studying an automated detection method using only post-event images in order to efficiently use the instantaneous acquisition ability of helicopters and airplanes [6, 7]. This study follows our previous work by investigating the suitability of this edge-based technique [8, 9], which was developed by examining the relationship between aerial images and detailed damage survey data obtained after the 1995 Kobe earthquake, on VHR satellite imagery.

Remotely sensed data and its derived information can be employed in a more attractive mean to strengthen public awareness in disaster mitigation. Virtual reality using remotely sensed data is widely employed to assist regional and local planning [10], to make digital cultural heritage [11], and numerous other applications. In this study, we develop a technique that employs the Digital Terrain Model (DTM), the building inventory database, and VHR satellite images for three-dimensional visualization and fly-over animation, which can assist on-site surveying and further damage assessment.

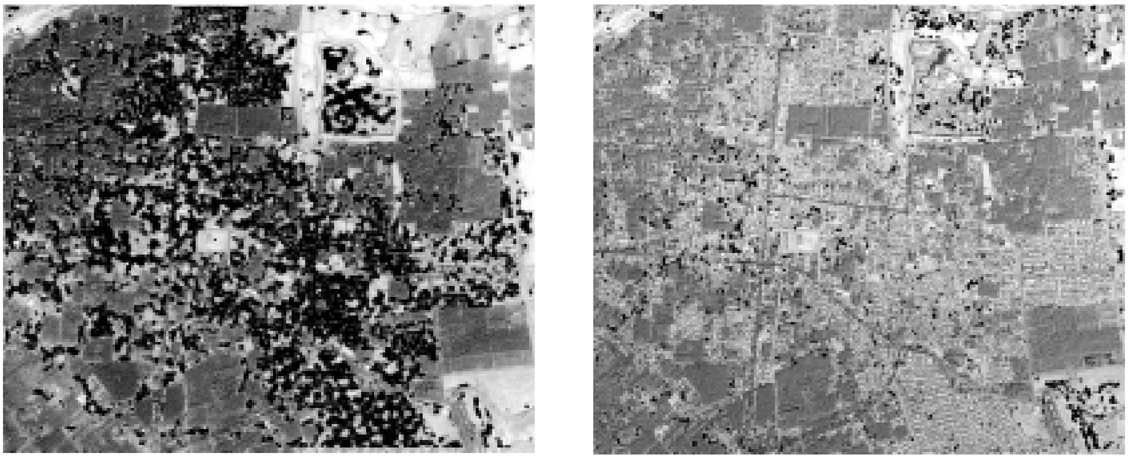
After the strong earthquake, which occurred beneath the city of Bam, Iran, on December 26, 2003, IKONOS and QuickBird observed the city on December 27, 2003 and January 3, 2004, respectively. QuickBird also captured the same area about eight months prior to the earthquake. These images are employed to demonstrate the competence of our methods. The following sections start with a description about the methodology for automated damage detection using high-resolution imagery and its application on VHR satellite imagery using data from Bam earthquake. Then the technique for making animation and visualization was applied to the Bam earthquake.

AUTOMATED DAMAGE DETECTION OF BAM EARTHQUAKE

The characteristics of collapsed buildings were examined by processing aerial television images taken after the 1995 Kobe, Japan, the 1999 Kocaeli, Turkey, the 1999 Chi-chi, Taiwan, and the 2001 Gujarat, India earthquakes [4]. Then, we proposed an area-independent technique to estimate the areas with damaged buildings using edge information in local windows, such as edge variance and edge direction, and statistical textures derived from the co-occurrence matrix of the edge intensity. Since the edge information can be derived from a gray scale image and brightness, the proposed method can be applied to the VHR satellite imagery with a spatial resolution of one-meter or less.

In our method, which is based on aerial television images, a gray scale (brightness) image was prepared from the original RGB image. IKONOS and QuickBird can capture panchromatic images with very high-resolution, about 1 meter and 0.6 meter, respectively. However, both panchromatic sensors cover the visible and the near-infrared region. Therefore, high-resolution brightness images were derived from pan-sharpened color images, which were created by combining the panchromatic band and multi-spectral bands. To create natural color images, we used linear contrast stretching, 2% for the minimum and 98% for the maximum and allocated band 1, 2, and 3 corresponded to blue, green, and red colors, respectively.

Figures 1 (a) and (b) show the results of the damage detection method applied to the IKONOS and QuickBird images of central Bam, respectively. Vegetated areas were removed by thresholding the NDVI (Normalized Difference Vegetation Index). According to the reports of visual damage inspection from QuickBird images [12] and a reconnaissance field survey [13], more than 80% of buildings in southern Arg-e-Bam were classified as Grade 4 (very heavy damage) or 5 (destruction) on the European Macroseismic Scale [14]. The distribution of detected damage from IKONOS was consistent with these results. However, less damage information was detected from the QuickBird image (Figure 1b). Spatial resolution and color distribution might be factors affecting the results.



(a) IKONOS image taken on 12/27/2003 (b) QuickBird image taken on 1/3/2004

Figure 1. Results of detected areas with damaged building.

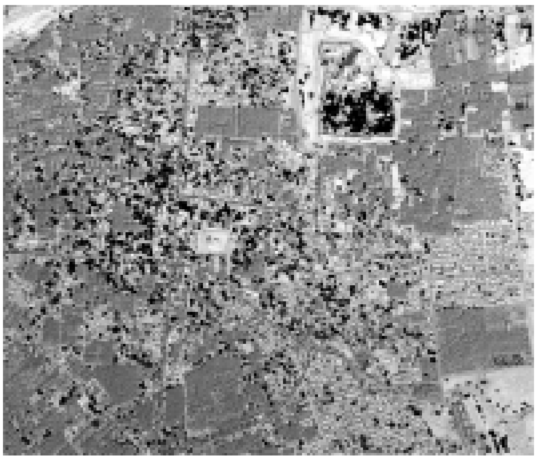


Figure 2. Distribution of detected damage areas using color-modified QuickBird image.

First, we examined the influence of the spatial resolution. However, a re-sampled, one-meter resolution, QuickBird image provided a similar result as the original QuickBird image. Hence, spatial resolution does not affect the extraction results. Next, We also calculated the rates of DNs of green and blue to that of red in pan-sharpened images to examine the color contribution. The average rates of green and blue to red values were 0.97 and 0.95 for IKONOS, 1.03 and 1.14 for QuickBird, which implies that the QuickBird image is predominantly cyan. In fact, a QuickBird image does not look natural, but has a blue tint. Therefore, the color of the QuickBird image was modified by histogram matching with the IKONOS image. Figures 2 and 3 show the results of damage detection using the color-modified QuickBird image and the damage distribution corresponded to the results of the aerial and field investigations. In addition, the detected results from the color-modified and re-sampled QuickBird image are similar to the results from the IKONOS image. The detection is mainly influenced by the color distribution among red, green, and blue channels.

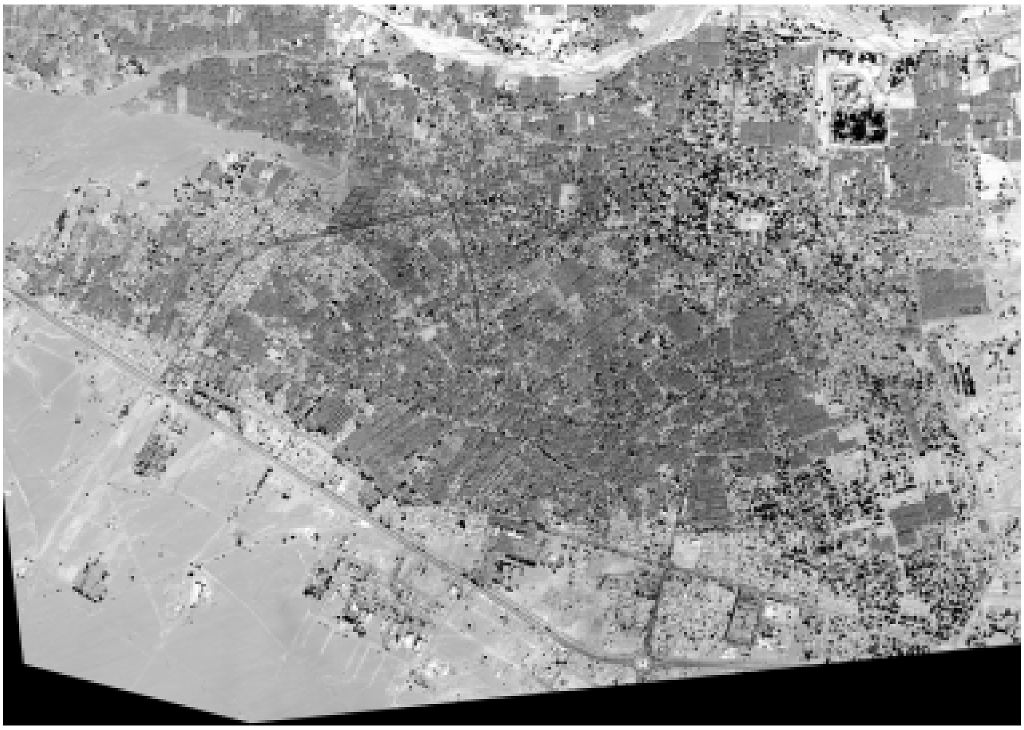


Figure 3. Distribution of detected damage areas in Bam city using color-modified QuickBird image.

FLY-OVER ANIMATION OF BAM EARTHQUAKE

Briefly, the three-dimensional visualization and animation are based on overlaying VHR satellite images on the Digital Surface Model (DSM). Focusing on buildings in urban areas, DSM is generated from the Digital Terrain Model (DTM) and the building inventory database. Other features such as the trees, parks, and streets are not used to generate the DSM. Consequently, the DSM is generated and converted into a grid format. The cell size of grid is the same as spatial resolution of satellite imagery. Both pre-event and post-event images are overlaid on grid-based DSM. A linear or cubic convolution re-sampling method is used to paint texture on the walls of buildings. The look angle, flight orbit, flight altitude, and flight speed are required parameters for the animation. The time frame is also decided to catch the scenes. The time-series scenes then are arranged and merged for animation (Figure 4).

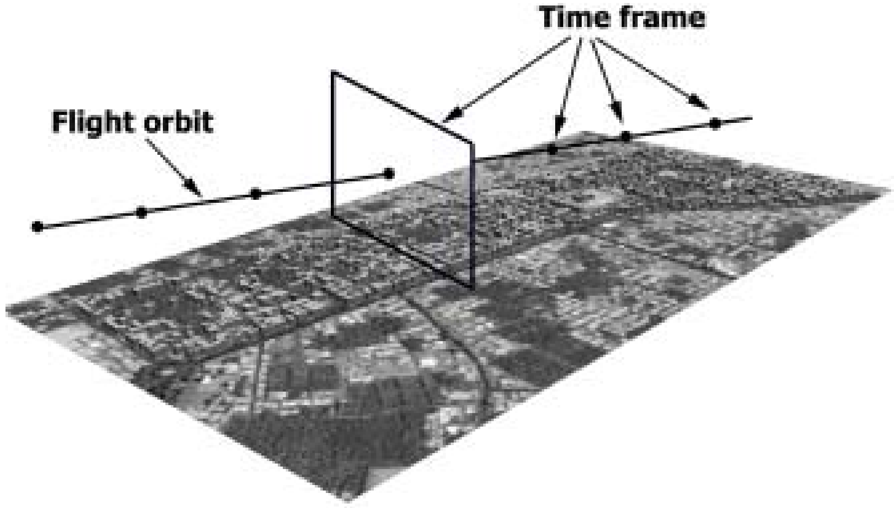


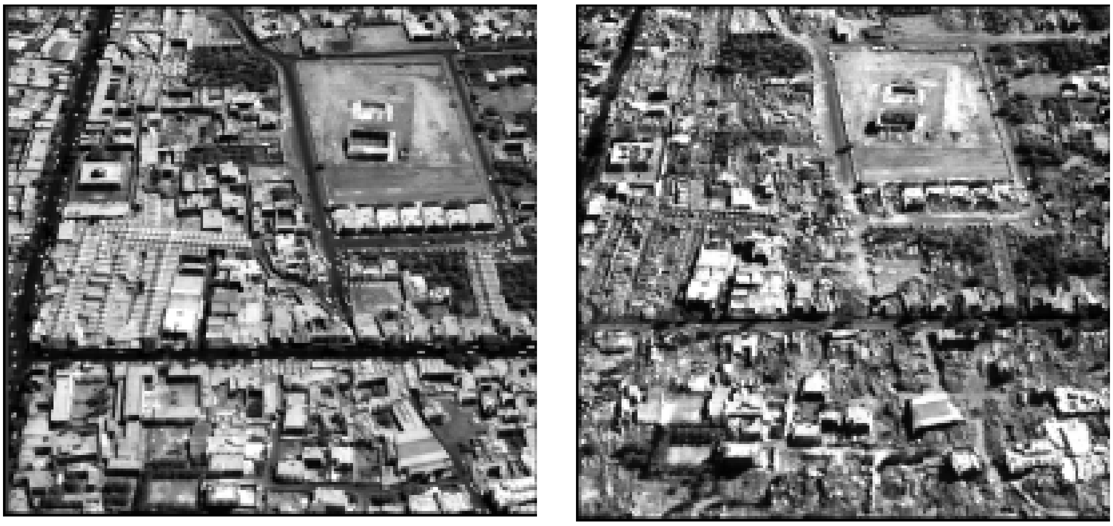
Figure 4. Illustration of determined flight orbit and time frames

For the Bam earthquake, DTM and building database were unavailable, but we were provided two QuickBird scenes: a pre-event scene acquired on September 30, 2003 and a post-event scene acquired on January 03, 2004. Without DTM, we assumed the area was flat. Building footprints were digitized from the pre-event scene to generate the building database. The relative heights of buildings were subsequently estimated based on the extracted shadows from this pre-event scene and were registered into building database. As observed in the QuickBird scenes of Bam, most houses are low and do not differ in height. Hence, the thickness of the extracted shadow was classified into 4 classes to estimate building heights. The extraction, classification, and registration of height into database were automatic. However, a visual inspection of the results was necessary to correct the strange appearance of some of the buildings due to the automated process being based solely on the extracted shadows. Finally, the animations for both pre-event and post-event QuickBird scenes were produced. Horizontal, vertical look angles, and flight altitude were 5 degree, -45 degree and 500 meter, respectively. These parameters were varied to generate different footages.

The captured scenes from pre-event and post-event fly-over animation are shown in Figure 5. Viewed in an oblique geometry, damaged buildings are clearly seen from these visualized scenes. The fly-over animation can also project two cameras on the same surveying flight. While the left camera shot the movie over the pre-event scene, the right camera shot the movie over the post-event scene with the overlaid damaged detection results (Figure 6).

CONCLUSIONS

An automated damage detection algorithm was developed to detect damaged buildings from VHR satellite data. The results using our method to analyze the 2003 Bam earthquake demonstrated the capability of our algorithm. We found that the color distribution of the RGB channels is critical and that the color distribution depends on the characteristic of each sensor. By modifying this distribution, our method was successfully implemented with VHR satellite imagery. A proposed scheme for fly-over animation and its amazing scenes from this 2003 Bam earthquake was initially aimed to assist the field-based damage estimation team. More importantly, this fly-over scheme can be used in disaster mitigation for the public. If VHR data is acquired within a reasonable time after a catastrophe, damage estimation in early stage is possible since our algorithm is a fully automated process.



Pre-event **Post-event**

Figure 5. Capture scenes from fly-over animation for pre- and post-event QuickBird images.

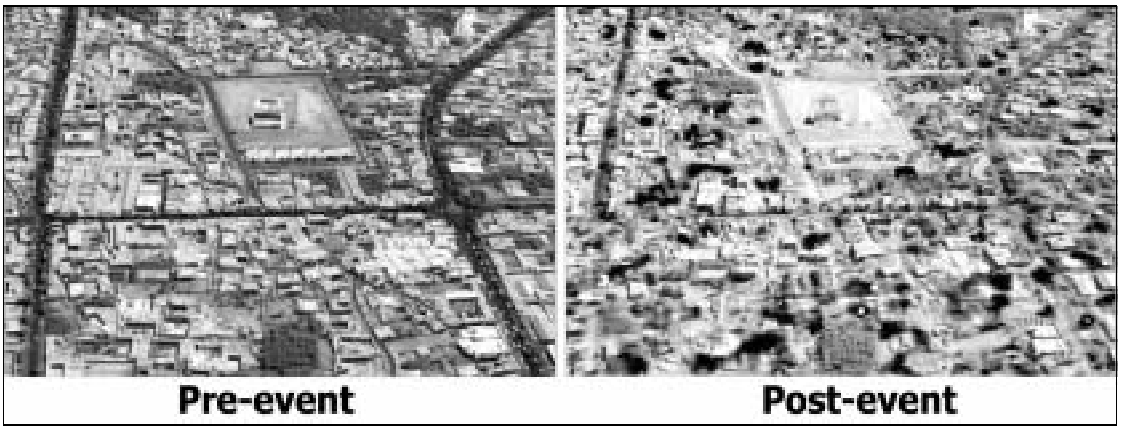


Figure 6. A captured scene of simultaneous fly-over animation.

ACKNOWLEDGMENT

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