USE OF DIGITAL AERIAL IMAGES TO DETECT DAMAGES DUE TO EARTHQUAKES

Fumio Yamazaki[1], Daisuke Suzuki[2] and Yoshihisa Maruyama[3]

[1] *Professor, Department of Urban Environment Systems, Chiba University, Japan*
[2] *Graduate Student, Department of Urban Environment Systems, Chiba University, Japan*
[3] *Assistant Professor, Department of Urban Environment Systems, Chiba University, Japan*
Email: yamazaki@tu.chiba-u.ac.jp

ABSTRACT :

Digital aerial cameras, recently introduced to aerial photography, have much higher radiometric resolution than traditional film aerial cameras do. Thus, even though the spatial resolution is almost the same level, a digital aerial camera can capture much clearer images of the earth surface than a film camera does. This paper highlights the capability of digital aerial images in detecting various damages due to earthquakes. In the recent earthquakes in Japan, such as the 2004 Mid-Niigata earthquake and the 2007 Off-Mid-Niigata earthquake, the affected areas were captured by digital aerial cameras as well as by analog aerial cameras and high-resolution satellites. In this paper, the quality of digital aerial images is first compared with scanned analog photos. Then the digital aerial images taken before and after the 2007 Off-Mid-Niigata earthquake are used to detect building damage. Both the pixel-based classification and the object-based classification are conducted. Debris of collapsed buildings is extracted correctly from the digital image processing.

KEYWORDS: Digital aerial image, spatial resolution, building damage, the 2007 Off Mid-Niigata earthquake, debris, object-based classification

1. INTRODUCTION

Aerial photography has been used widely for aerial surveying and photogrammetry. Because of its very high spatial resolution, aerial photographs were employed to detect damages due to earthquakes (e.g., Ogawa and Yamazaki, 2000). Digital aerial cameras, recently developed and introduced for aerial photography, have much higher radiometric resolution than traditional film (analog) aerial cameras do. Thus, even though the spatial resolution is almost the same level, e.g. 0.1 m, a digital aerial camera can capture much clearer images of the earth surface than an analog camera does.

Another important feature of digital aerial cameras is that they have a near infrared (NIR) band as well as RGB visible bands. Using the NIR band, detection of vegetation becomes quite easy. Through the pan-sharpening procedure, very-high resolution pseudo-color images can be obtained by combining these 4 multi-spectral bands and the panchromatic band. Note that the spatial resolution of high-resolution satellites currently available is 0.6 m (QuickBird) at the maximum, and thus the digital aerial images can be used for extraction of detailed damages of buildings and infrastructures (Mitomi et al., 2002; Maruyama et al., 2006).

This paper highlights the capability of digital aerial images in detecting various damages due to earthquakes. In the recent earthquakes in Japan, such as the 2004 Mid-Niigata, the 2007 Noto Peninsula, and the 2007 Off-Mid-Niigata earthquakes, the affected areas were captured by digital aerial cameras as well as by film aerial cameras and high-resolution satellites. Especially for the 2007 Off-Mid-Niigata earthquake, digital aerial cameras captured the affected area both before and after the event. Image processing techniques are applied to those digital images, and the image processing methods to extract damage to buildings are discussed.

2. DIGITAL AERIAL IMAGES OF KASHIWAZAKI CITY

The central part of Niigata Prefecture, Japan was hit by a strong M_{JMA}=6.8 earthquake on July 16, 2007. A total 1,330 houses were collapsed or severely damaged and 15 people were killed in Niigata Prefecture. Kashiwazaki City was most severely affected in the prefecture with 1,120 collapsed or severely damaged houses and 14 deaths. A fire broke out in Kashiwazaki-Kariwa nuclear power plant from a transformer. Due to the strong shaking exceeding the safety shutdown level, the operation of the power plant has been suspended since then.

Figure 1 shows the central part of Kashiwazaki City. Aerial surveys of the city were conducted by three different organizations as shown in Table 1; Kashiwazaki City Government on 27 April, 2007 (before the earthquake), Asia Air Survey Co., Ltd. and Geographical Survey Institute (GSI), Japan on 19 July, 2007 (two days after the earthquake). The pre-event images of the city government were taken by UltraCam-D digital camera (Leberl and Gruber, 2005) while the post-event images of Asia Air Survey were obtained by DMC digital camera (Hinz, 1999). UltraCam and DMC are the most selling large-format aerial digital cameras in the world.

Figure 1 Central part of Kashiwazaki City by Google Earth and the target area of this study (yellow square)

Table 1 Three aerial images of Kashiwazaki City before and after the July 16, 2007 Off-Mid Niigata earthquake

Image			
Acquisition Date	2007. 4. 27	2007. 7. 19	2007. 7. 19
Camera	Ultra Cam D digital	DMC digital	RC30 analog
Data Owner	Kashiwazaki City	Asia Air Survey Co., Ltd.	Geographical Survey Institute, Japan
Ground resolution	16.9 cm	12.2 cm	20.2 cm (after scanning)
Pixel size	532×379	720×532	389×278

One of the most advantageous features of aerial digital cameras is that they have a near infrared (NIR) band as well as RGB visible bands. Vegetation is often the cause of changes between two images taken in different seasons. However, using NIR and red (R) bands of digital cameras, vegetation is easily extracted in terms of the normalized vegetation index (NDVI), calculated by NDVI = (NIR - R) / (NIR + R), where R and NIR are the reflectance of the red and near-infrared bands, respectively. NDVI is a simple and reliable index to identify the existence of vegetation, and therefore widely applied to assess the characteristics of the earth surface in the field of satellite remote sensing. Figure 2 compares the NDVI values before and after the event. Since the pre-event image was taken in spring and the post-event in summer, much active vegetation is seen in the post-event image. This kind of seasonal changes should be removed before performing change detection due to earthquakes.

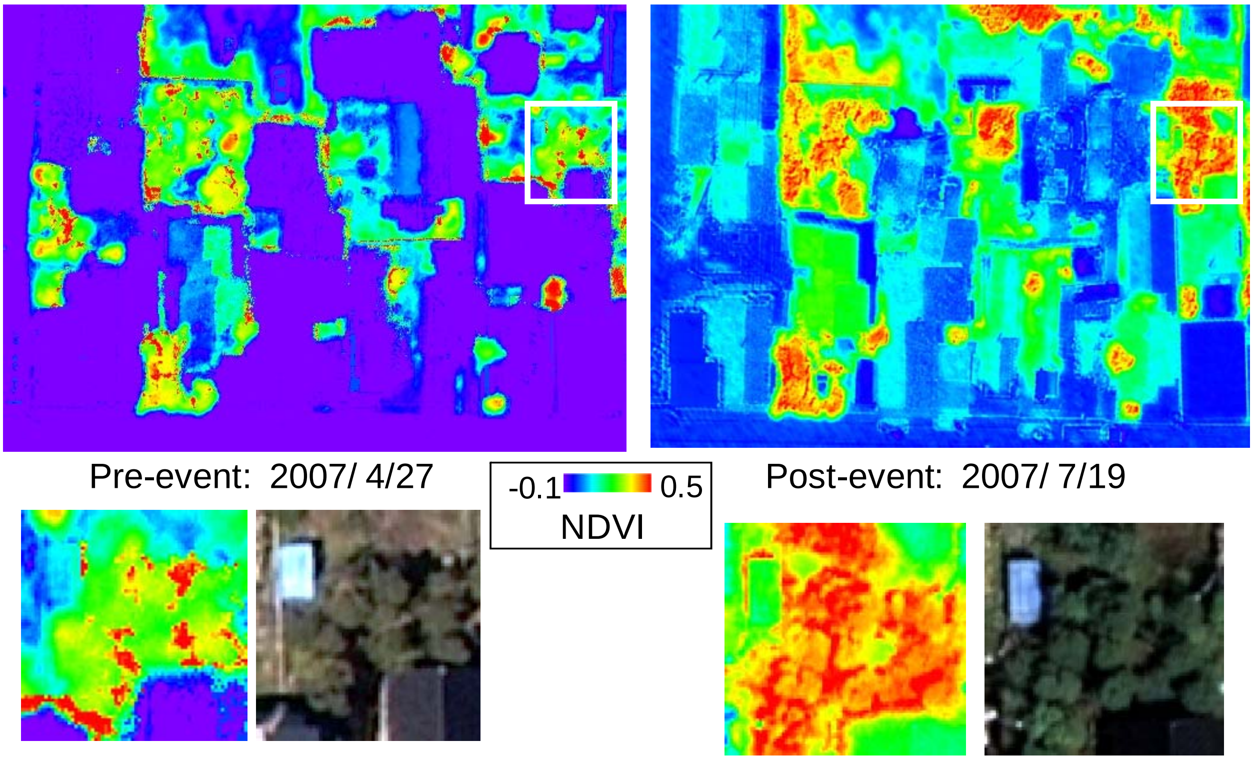

Figure 2 Comparison of NDVI for the pre-event and post-event digital images. Difference of vegetation due to different season is clearly seen.

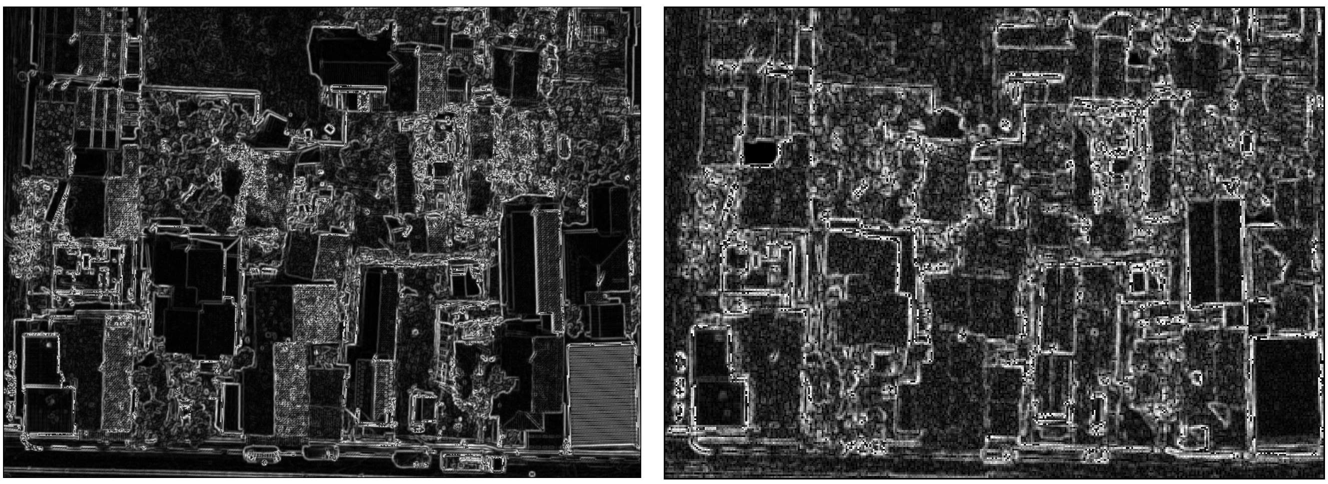

Figure 3 Comparison of edges extracted from the post-event digital image (left) and from the post-event scanned-analog image (right).

Another important feature of digital aerial images is its high radiometric resolution. Since digital images contain much less noise than scanned-analog photos do, much clear edges can be extracted. Figure 3 compared the results of edge extraction using Prewitt filter (3x3) from the post-event digital image and the post-event scanned-analog image. The extracted edges from intact buildings are straight and sharp for the digital image. A lot of salt-and-pepper noises are seen in the analog image while those are few for the digital image. Edge extraction is one of the important tools to extract building damage (Mitomi et al., 2002), to estimate the overturning ratio of tombstones due to earthquakes (Nitto and Yamazaki, 2006), and to extract vehicles from aerial images (Liu et al., 2007). The edges of vehicles are clearly recognized in the digital image of Figure 3 while they are not so clear in the scanned-analog image.

3. PIXEL-BASED CLASSIFICATION

First, a conventional pixel-based classification was carried out based on the maximum likelihood method, the most common supervised classification method. In the classification, 8-bit data value (0-255) of blue, green, red, and near-infrared bands were used. Eight classes: black-roof, gray-roof, red-roof, white-roof buildings, road, ground, tree, and grass, were assigned for the pre-event image as training data, as shown in Figure 4. Shadow was not classified as a class because its brightness is difficult to separate from that of black-roof.

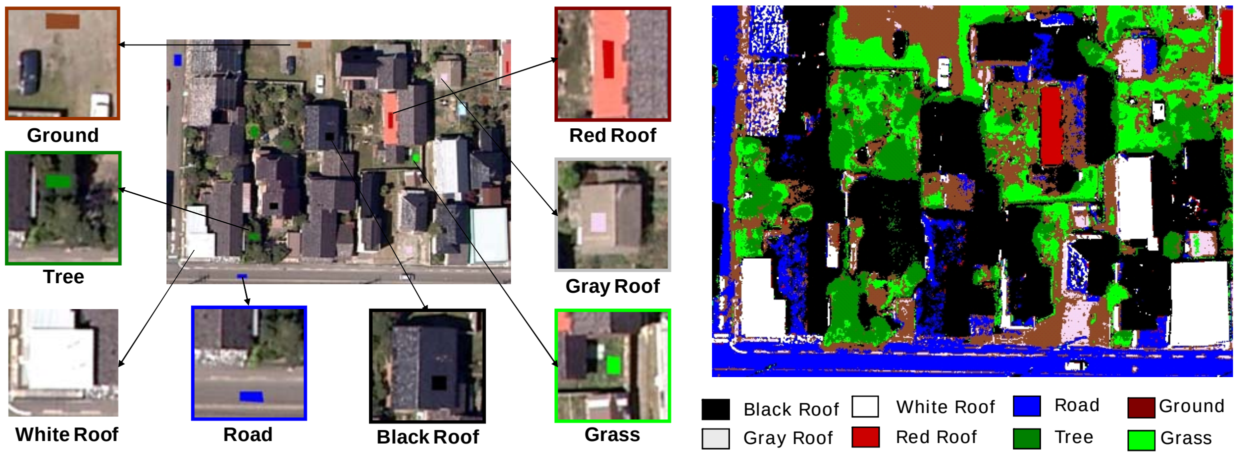

Figure 4 Classes and training data of supervised classification for the pre-event digital image (left) and the result of classification (right).

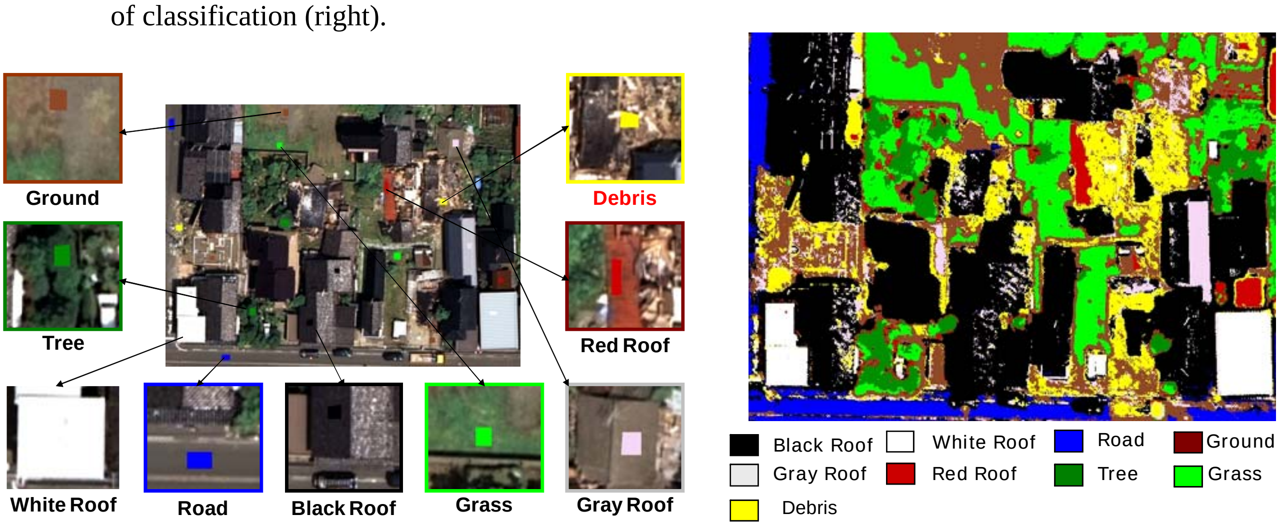

Figure 5 Classes and training data of supervised classification for the post-event digital image (left) and the result of classification (right).

The result of classification looks, in general, reasonable. Especially vegetation was correctly classified because NIR band was used in the classification. The buildings were classified into 4 classes based on their roof color, and hence some misclassifications are seen, especially for the roofs with dark color roof-tiles. As the characteristics of pixel-based classification and due to very-high spatial-resolution of the digital aerial image, salt-and-pepper noise is seen (Matsumoto et al., 2006) in the classified result.

For the post-event digital image, 9 classes, which correspond to the 8 pre-event classes plus the debris class, were assigned as shown in Figure 5. The result of the supervised pixel-based classification is also shown in the figure. The area classified as the debris class looks more than the actual debris, consisting of the mixture of woods, mud, and roof-tiles. Since debris does not have unique spectral characteristics, commission error might be occurred by pixel-based classification methods. Mitomi et al. (2002) introduced a sort of spatial filtering to reduce the salt-and-pepper noise classified as debris. In such approaches, the size of spatial window should be assigned properly, depending on the size of target objects.

4. OBJECT-BASED CLASSIFICATION

To solve the salt-and-pepper problem in high-resolution images, object-based classification has recently been introduced. Yamazaki and Kouchi (2006) compared the result from pixel-based classification and that from object-based one for debris detection using QuickBird images in the 2003 Boumerdes, Algeria earthquake. In the study, however, only the post-event image was used and thus, pre-event information, e.g. the location of buildings, was not used effectively. Usefulness of object-based classification is further investigated by Matsumoto et al. (2006) in building damage detection from QuickBird images obtained before and after the 2006 Central Java earthquake. Building areas are extracted for both pre-event and post-event images by pixel-based and object-based classifications. The results showed that the object-based method is suitable to reduce the noise to extract debris from other objects.

In the present study, the digital aerial images with much finer spatial-resolution were employed in performing object-based classification using e-Cognition software. Image segmentation was carried out as the first step to make “objects” using the pre-event and post-event images. In e-Cognition, the segmentation process is determined by 5 parameters: Layer Weight, Compact Weight, Smooth Weight, Shape Factor, and Scale Parameter (Baatz et al., 2004). The most important parameter is Scale Parameter, which determines the object size. Shape Factor is to determine the importance level of spectral heterogeneity or shape heterogeneity in segmentation. When the shape factor moves toward 0, the spectral heterogeneity is more concerned. On the contrary, if it moves toward 0.9, the shape heterogeneity is more concerned. In further details, the spectral heterogeneity is decided by Layer Weight, which gives the weight for each band. The shape heterogeneity is decided by Compact Weight and Smooth Weight. The bigger the compact weight is, the segmented object is in a more compact shape. Alternatively, the bigger the smooth weight is, the segmented object is in a more smooth shape.

Starting from pixels, segmentation runs the merger between two objects and is terminated when an assigned condition is reached. This condition is defined based on the fusion value f, which measures the changes when merging and decided by Layer Weight, Compact Weight, Smooth Weight, and Shape Factor. If f equals to or becomes bigger than the squared scale parameter, the condition is reached. Although it is difficult to decide the appropriate values of the parameters suitable to all land cover classes, the user can decide the suitable values to a few focused classes, e.g. building, road, and car.

The appropriate parameters for the size of a car was used in this study because the aerial images have very high spatial-resolution and we want to extract debris larger than say, 3-5 m. Figures 6 and 7 show examples of image segmentation for the pre-event and post-event images, respectively, by changing the value of Scale Parameter. Considering its resolution (16.9 cm) and the target size of objects (car), Scale Parameter was determined as 30 for the pre-event image while it was determined as 40 for the post-event one based on its resolution (12.2 cm).

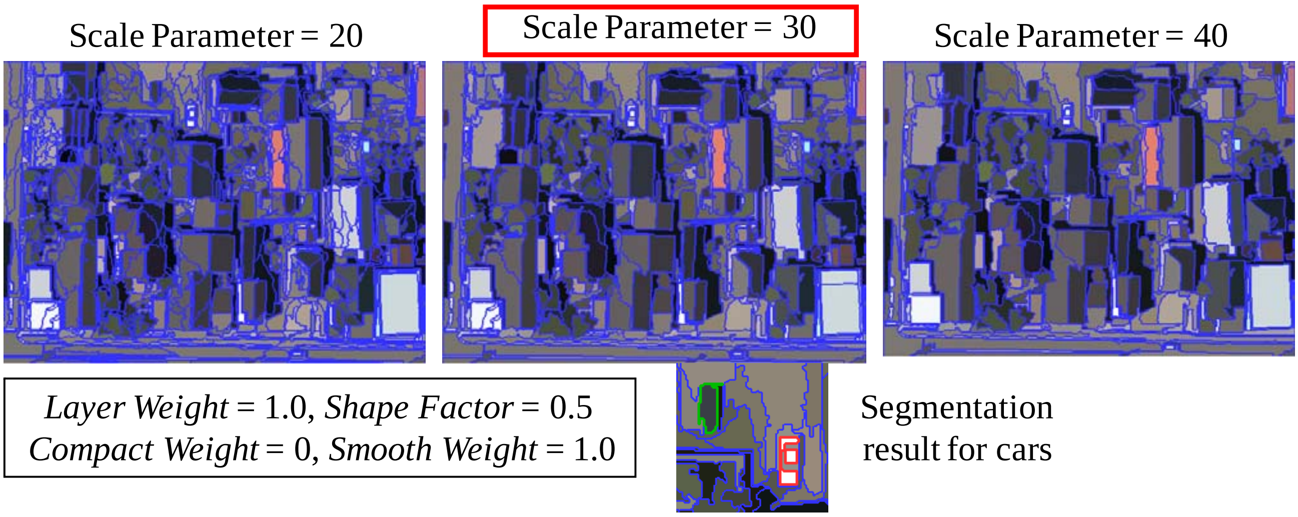

Figure 6 Examples of image segmentation for the pre-event image. Scale Parameter= 30 is used for the further study considering its spatial resolution (16.9 cm) and the target size of objects (car).

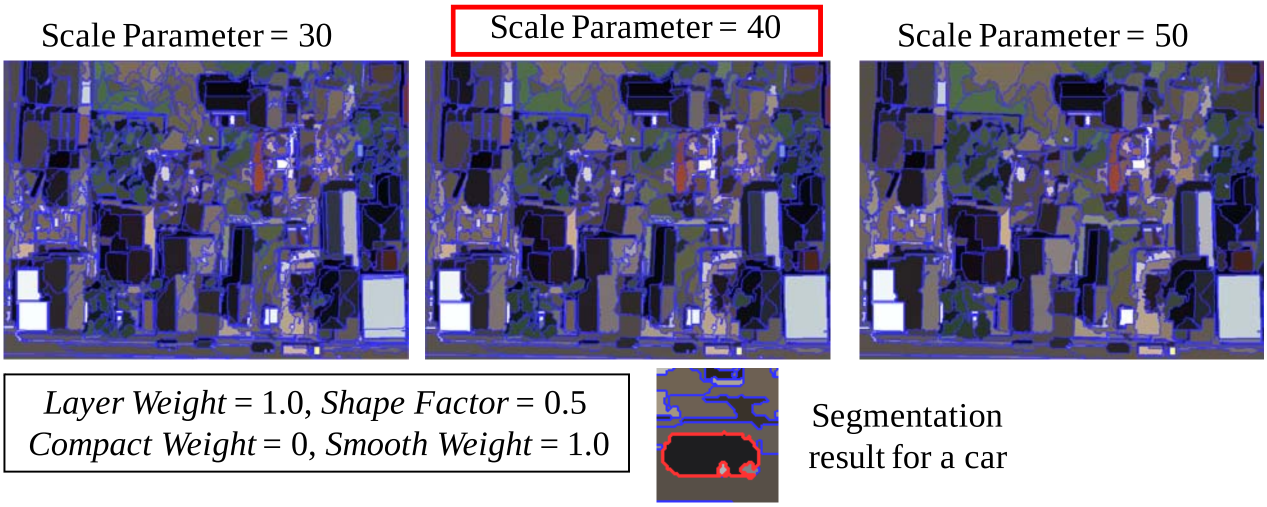

Figure 7 Examples of image segmentation for the post-event image. Scale Parameter= 40 is used for the further study considering its spatial resolution (12.2 cm) and the target size of objects (car).

After segmentation, the samples for all the classes were selected as the same areas in the pixel-based classification. The objects' mean values of blue, green, red, and near-infrared were used as the indices of supervised classification and the nearest neighbor method was employed. The results of the object-based classification for the pre-event and post-event images are shown in Figure 8.

Comparing the results from the pixel-based classification (Figures 4 and 5) and those from the object-based classification, the later method looks to classify the images into proper object groups. Salt-and-paper noises are no more seen in case of the object-based classification. Comparing the classification results with visual inspection, some gray roofs were classified as road for the pre-event image because their colors are close. A similar misclassification is seen among black and gray roofs and road for the post-event image. Debris class is rather well classified in the object-based method because of its segmentation process. It may be concluded that in this very high-resolution and the sizes of the target objects, the better result can be acquired by object-based classification. But more case studies are necessary because the object-based method requires the process to determine appropriate parameter values.

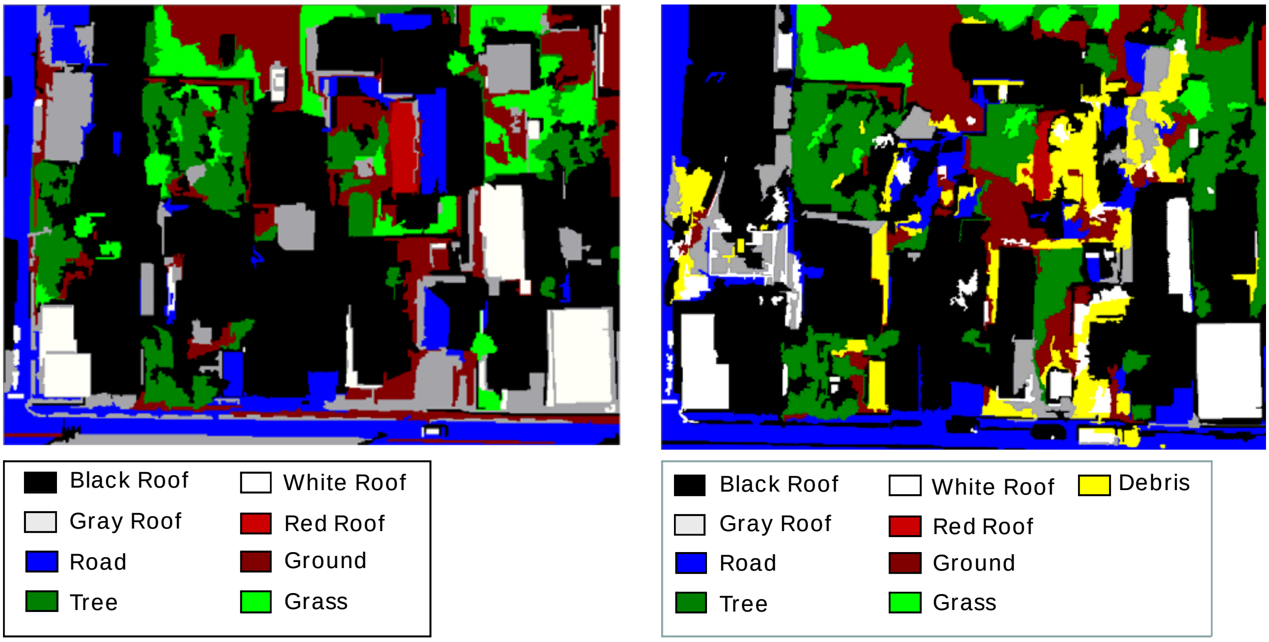

Figure 8 The results of the object-based classification for the pre-event image (left) and the post-event image (right).

CONCLUSIONS

Extraction of building damage was conducted using digital aerial images for a residential area in Kashiwazaki City, captured before and after the 2007 Off-Mid-Niigata earthquake. First the advantages of digital aerial cameras were highlighted. Due to their very-high spatial resolution, digital aerial cameras can provide fine details of urban areas, including damages from natural disasters. Very sharp and clear edges can be obtained and they can be utilized to extract small objects like cars and debris. The near infrared band of digital cameras is considered to be a powerful tool to extract vegetation, which often causes changes between the images acquired in different seasons.

Image classification was carried out by pixel-based and object-based methods for the pre-event and post-event images. Because salt-and-pepper noises were seen in the pixel-based classification result, the object-based classification is considered to be more suitable to classify very high-resolution aerial images of dense urban areas. To establish a general damage detection method in future, however, more parametric studies must be necessary for various urban and rural environments.

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