Detection of Building Damage due to the 2006 Central Java, Indonesia Earthquake Using Satellite Optical Images

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ABSTRACT

In order for emergency response and early recovery assessment in large-scale disaster, it is important to rapidly comprehend the extent and severity of the building damage. In the 2006 Central Java, Indonesia, earthquake (M6.3), severe building damage was observed in and around Yogyakarta city. A building damage detection technique is applied to satellite optical images observed before and after the earthquake. The satellite FORMOSAT-2 images whose spatial resolution is 2m are used in this study. The comparison of the images reveals that spectral reflectance of the post-event image is higher in severely damaged areas than that of the pre-event image. This may be because that bricks of building walls brighter than roof tiles are exposed to the ground surface due to the collapse of buildings. The pixels whose digital numbers are remarkably increased after the earthquake are extracted as the severely damaged areas. The result shows that the distribution of the detected damage areas is similar with the actual damage distribution compiled by the regional officials.

INTRODUCTION

Rapidly quantifying the extent and severity of building damage is a high priority in the aftermath of large earthquake. In the Central Java, Indonesia earthquake of May 27, 2006 (M6.3), severe building damage was observed in and around Yogyakarta city. About 5,800 were killed and 38,000 were injured due to the earthquake. About 140,000 houses were completely collapsed, and 190,000 houses were severely damaged. Damage distribution map have been estimated using remote sensing data observed after the earthquake (e.g., UNOSAT 2006 and RESPOND 2006). The maps were delineated based on the visual detection using high-resolution satellite images such as QuickBird images. However, the visual detection requires a great demand of labors and the result depends on skills of the operators. Automated or semi-automated damage detection technique would be helpful to quickly identify damaged areas for more rapid damage assessment. In this study, a building damage detection technique is applied to satellite optical images observed before and after the earthquake.

CHARATERISTICS OF SATELLITE OPTICAL IMAGES

Images of the satellite FORMOSAT-2 launched by Taiwan in May 2004 are used in this study. The satellite provides a panchromatic (black/white) image whose spatial resolution is 2m and a multi-spectral (color) image whose resolution is 8m. The multi-spectral image consists of four bands (Band1: Blue, Band2: Green, Band3: Red, Band4: Near infrared). The off-nadir view angle of the satellite is usually constant, while the view angles of other high-resolution commercial satellite such as QuickBird and IKONOS are often changed from observation to observation to capture a target area in a short time interval. The constant view angle would make it easier to exactly overlay a pair of images acquired in different date. Besides, the image width of FORMOSAT-2 is about 25km, while the width of the other high-resolution satellite images is only 10-15km. They are great advantages of FORMOSAT-2 images in the detection of change between pre- and post-event.

Figure 1 shows the map of the epicentral area of the 2006 Central Java earthquake with the distribution of the ratio for severely damaged buildings after Murakami et al. (2006). Solid square indicates the area of the FORMOSAT-2 image used in this study. Figure 2 shows the pan-sharpened images observed before and after the earthquake. The characteristics of the images such as the observation date, the satellite angles and the sun angles are shown in Table 1. The pre-event image was observed nine days before the earthquake and the post-event image is acquired fifteen days after the earthquake. The time interval of the images is about 1 month.

The close-ups of the pre- and post-earthquake images are shown in Fig. 3.

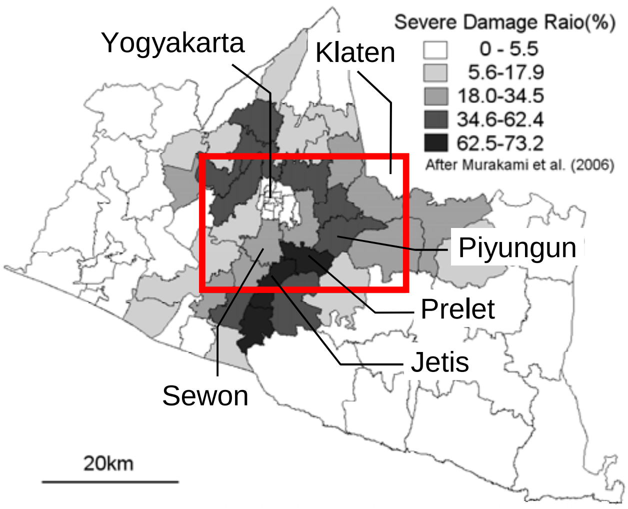

Fig. 1 Damage distribution in the 2006 Central Java earthquake with the area of interest

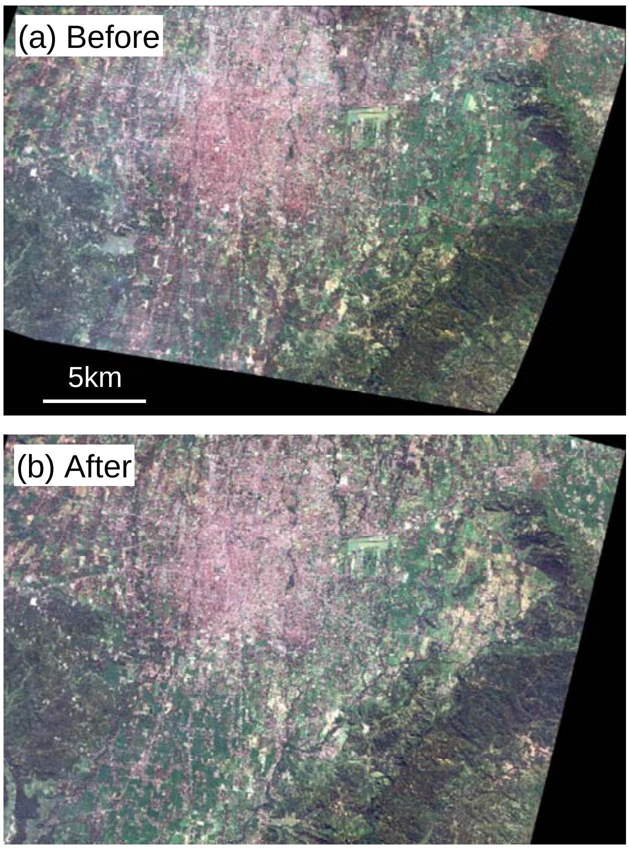

Fig. 2 FORMOSAT-2 images

Table 1 Characteristics of FORMOSAT-2 images

Event	Date	Time	Satellite Azimuth (deg.)	Satellite Elevation (deg.)	Sun Azimuth (deg.)	Sun Elevation (deg.)	Spatial Resolution (m)
Before	May 18, 2006	AM 09:09	N103.2E	28.8	N52.3E	44.9	2.0
After	Jun 11, 2006	AM 09:09	N102.8E	28.5	N48.7E	42.2	2.0

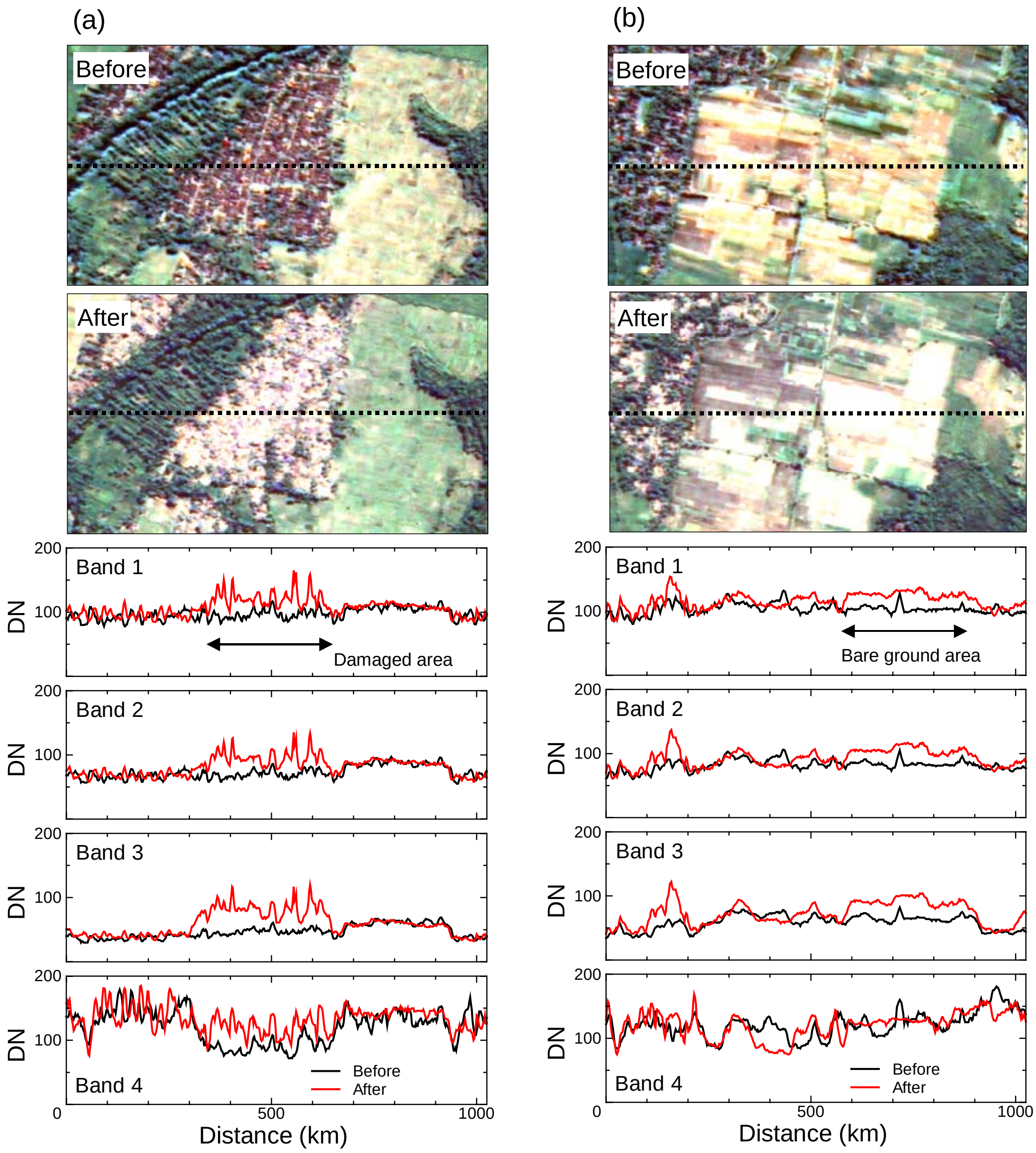

Fig. 3 Close-ups of the images and cross-sections of pixel values
(a) Severely damaged area, (b) Bare ground area

The cross-sections of pixel value (digital number: DN) along the dotted line in the images are also illustrated in Fig. 3. Black lines and red lines indicate the pixel value of pre- and post-event images, respectively. Figure 3(a) represents the close-up of a severely damaged settlement. As shown by the cross-sections in Fig. 3(a), the pixel values in the damaged area after the earthquake is higher than those before the event. In the severely damaged area, numbers of wall bricks and debris of buildings are exposed on the ground surface due to the collapse of buildings. Since the spectral reflectance of wall bricks is higher than the other building materials such as roof tile (Miura et al., 2007), the pixel values of the damaged area in the post-event image is higher than those in the pre-event image. It suggests a possibility to identify the damaged areas from the differencing of pixel values between the images.

Figure 3(b) shows the close-up of a bare ground area where rice paddies are cropped. The comparison of pre- and post-event images shows that the pixel value in the bare ground area after the earthquake is higher than that before the event. This may be because that the soil moistures are temporally changed in different observation date. When the damaged areas are detected by differencing of pixel values between the images, it is necessary to discriminate the damaged area with the bare ground area. The comparison of Fig. 3(a) and (b) shows that the spatial variation of pixel values in the damaged area is larger than that in the bare ground area. It would be possible to discriminate damaged area with bare ground area by using texture measures of the image. Since the difference of pixel values in the band3 is larger than the other bands, the band3 images are mainly used in the following steps.

DETECTION OF BUILDING DAMAGE AREAS

The flowchart of the proposed damage detection method is shown in Fig. 4. Firstly, the pre-event image is geometrically corrected to superpose the post-event image. The pixels of the image are broadly classified into three categories; vegetated area, bare ground area and built-up area. The vegetated areas such as paddy fields, grasses and forests are extracted using NDVI (Normalized difference vegetation index) computed from the post-event images. In this study, the pixels whose NDVI is higher than 0.4 are classified into vegetated area. Bare ground areas are extracted using the variance of pixel values that is one of the texture information. The variance of pixel values is computed for 7 by 7 pixel windowed area. The pixels whose variance is lower than 10 in the post-event image are classified into bare ground areas. The other pixels are classified into built-up areas. Finally, the pixels whose difference of pixel values between the images is higher than 20 are extracted as damaged areas.

The distribution of the damaged areas estimated by the proposed method is shown in Fig. 5(a). Black pixels indicate the detected areas. Numbers of pixels are detected in the southern, eastern and central part of the image. The estimated damage distribution is broadly divided into three regions as shown by dotted circles. The largest circle includes the southeastern areas such as Jetis, Prelet and Piyungun. The central circle covers the northern part of Sewon and the southern part of Yogyakarta and the northeastern circle contains Klaten.

The estimated damage distribution is compared with the damage map assessed by UNOSAT shown in Fig. 5(b). In the UNOSAT map, the visually detected damage was classified into three categories; extensive damage, moderate damage and limited damage. The extensive and moderate damage areas are concentrated in Jetis, Prelet and the southern part of Sewon. The limited damage areas are expanded to Piyungun. The damage is also distributed in the northern part of Sewon and the southern part of Kashihan. The damaged areas are mostly concentrated in the two of the dotted circles. Building damage in Klaten was not delineated in the UNOSAT map because most of the area was covered with clouds in the satellite images. The results indicate that the distribution of the pixels detected in this study shows good agreement with the UNOSAT damage map.

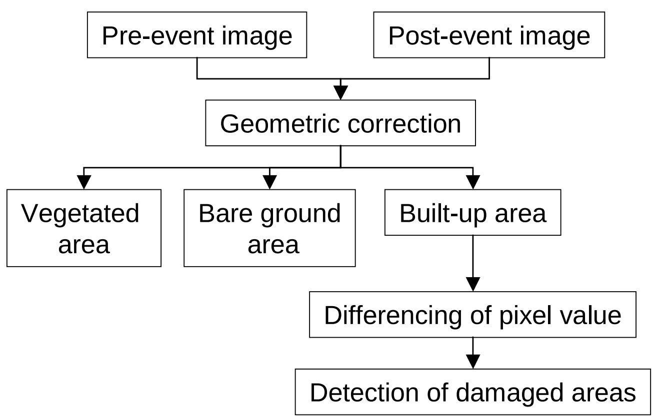

Fig. 4 Flowchart of building damage detection

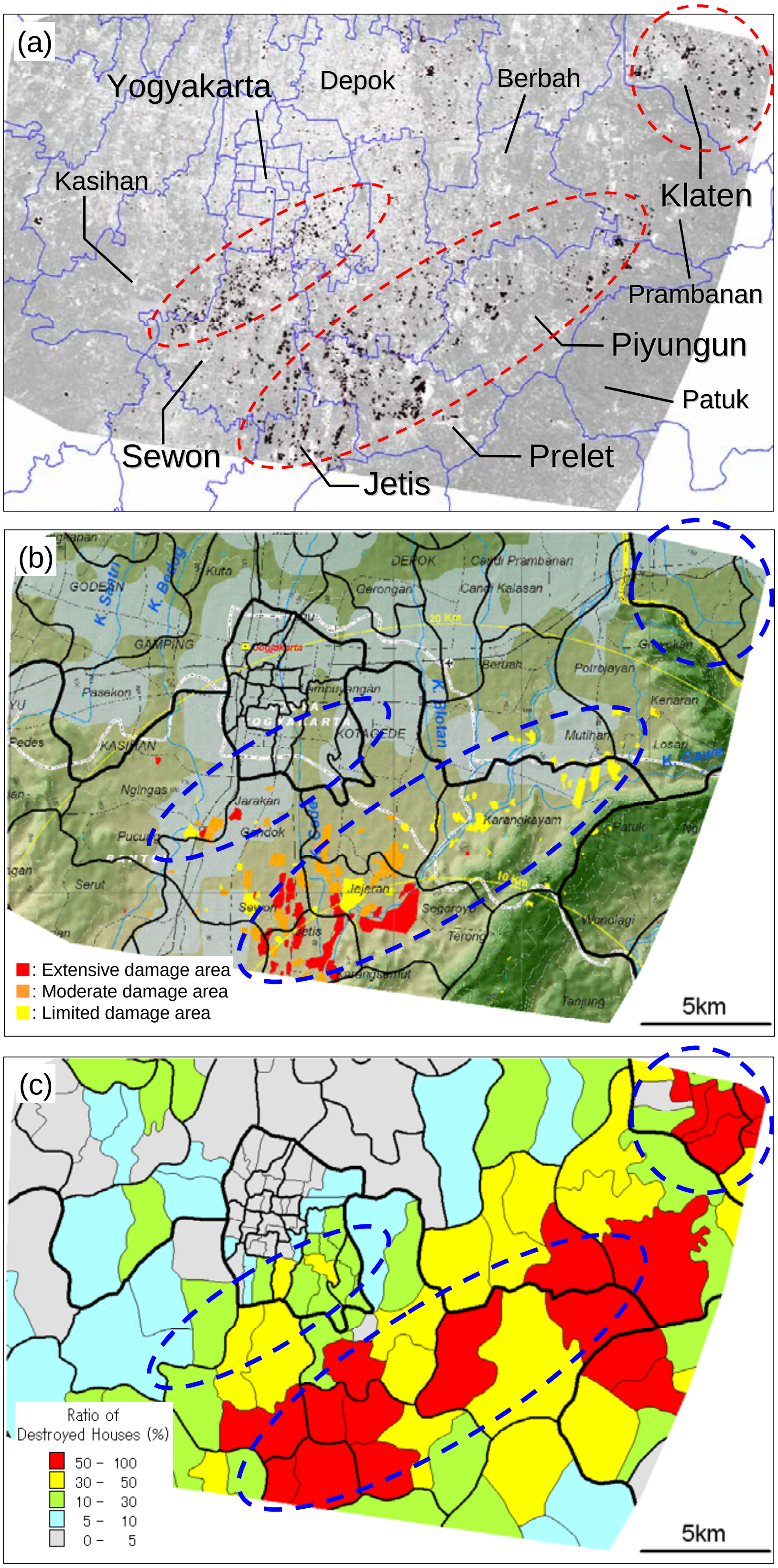

Fig. 5 (a) Distribution of detected pixels, (b) Damage map by UNOSAT,
(c) Distribution of damage ratio derived by damage statistics

The building damage statistics in the earthquake has been compiled by the regional officials of Yogyakarta and Central Java. The data was reported at the Desa (Village) level for about 1300 locations in 175 Kecatamans (Sub-districts) and 13 Kabupatens (Districts). The data includes total population, total number of households and number of damaged houses in each village. The building damage was classified into three categories; destroyed, heavy damage and slight damage. The damage ratio is calculated from the number of destroyed houses divided by the number of households in each village. Figure 5(c) shows the distribution of the ratio of destroyed houses.

As shown in Fig. 5(c), the severely damaged villages whose damage ratio is more than 50% are distributed in Jetis, Prelet, Piyungun, Prambanan, Berbah, Patuk and Klaten. The largest dotted circle in the figure covers most of the severely damaged areas. The northeastern circle also covers the severely damaged area in Klaten. The result shows that the distribution of the detected pixels is consistent with the actual damage distribution. However, the damage in Patuk and the southern part of Prambanan is not well detected in the analysis. This may be because that the villages are mainly located in the mountainous areas and numbers of the houses are not visually detectable even from the high-resolution image due to tall trees around the houses.

In this analysis, many pixels are mis-detected in Depok and the southern part of Yogyakarta, although the damage ratios are almost less than 30% and the building damage is not visually detected from the images. Most of the roofs of the mis-detected buildings show high reflectance in the images. Pixel values of satellite images temporally change and fluctuate even in non-affected areas probably due to atmospheric and moisture conditions. Since the temporal change of pixel values in such buildings is relatively larger than that in other buildings, the difference of pixel values is large even in non-damaged buildings. Adequate spectral correction of the images would be necessary to reduce these mis-detections.

CONCLUDING REMARKS

A methodology to semi-automatically detect building damage areas is applied to the FORMOSAT-2 images observed before and after the 2006 Central Java, Indonesia earthquake. Using NDVI and texture measure, pixels in the image are classified broadly into three categories; vegetated area, bare ground area and built-up area. The damaged areas are detected from the difference of pixel value in the built-up areas between the images. The detected damaged areas are verified with the damage distributions by the visual detection of high-resolution satellite images and by the damage statistics. The result shows that the severely damaged areas mostly identified. However, mis-detections are induced due to the temporal changes of the pixel values.

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