Detection of Earthquake Damaged Areas from Aerial Photographs by Using Color and Edge Information

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Abstract

To grasp the range and seriousness of the damage is indispensable for starting up quickly life supporting activities after a wide area disaster, such as a big earthquake. In this study utilization of aerial photograph images for this purpose is considered. We investigated two cases: (1) only an aerial photograph after the earthquake is available, and (2) aerial photographs of the same area before and after the earthquake can be used.

In the first case, color and edge information is used for detecting the damaged areas. We detect brown areas in the hue image, and also areas where the number of edges is large and edge orientations are somewhat uniform in the lightness image. Then we make their intersection.

In the second case, we first match two images by specifying several corresponding points by hand and by applying an affine transformation. Checking colors of each corresponding pixel pair in the matched two images, we detect areas having color differences to some extent. We apply different criteria to chromatic colors and nonchromatic colors for compensation of the difference of light and view conditions of the two images taken.

Both methods yield fairly good detection of areas damaged by an earthquake.

1. Introduction

When a wide-area natural disaster such as a big earthquake occurred, the range and seriousness of its damage should be quickly grasped in order to make a plan for life supporting activities. With human works only, it is difficult to estimate the damages in a global area. For this reason we investigated usability of image processing techniques applied to aerial photographs.

Ideally, aerial photograph images should be prepared before the disaster (i.e., in an ordinary situation), and aerial images immediately after the disaster be compared with the former ones. However, we also considered the case that such an ordinary image is not available. Thus we consider two cases: (1) only aerial photographs after the earthquake are available, and (2) aerial photographs of the same area both before and after the earthquake can be used.

In the following sections, we will describe two methods, one for each case above, of detecting areas damaged by an earthquake.

We explain about the Hue-Lightness-Saturation (HLS) color model here, because both methods use color features defined on this model. The HLS color model (Figure 1) is defined by two hexcones placed base to base, with black at one apex and white at the other. In this model, black has a lightness of 0 and white a lightness of 1. Hue is the angle around the vertical axis of the double hexcones, with red at 0 degree. The colors occur around the perimeter in the order: red, yellow, green, cyan, blue, and magenta. Saturation is measured radially from the vertical axis, from 0 on the axis to 1 on the surface.

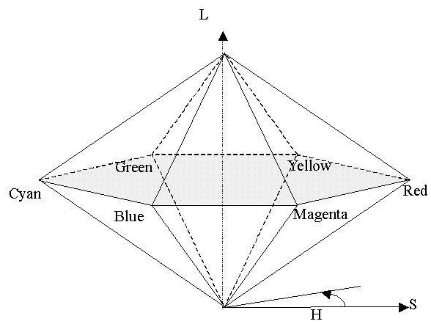


Figure 1. HLS color model

2. Method I: Detection from a single aerial image

In this section, a method is described for detecting areas of collapsed buildings from a single aerial image taken after an earthquake.

In aerial photographs a damaged area of collapsed buildings usually has brown random texture. Hasegawa et al. [1] proposed a method of detecting damaged areas by combining brown color areas in the hue image and areas where edge intensities have small variances. However, in this method non-damaged areas are also detected, such as railroad tracks, which have also a brown color and many small edges.

To solve this problem, we try here to use edge direction information for discriminating damaged areas with randomly directed edges and non-damaged artifacts with aligned edges. Then we propose a method to detect areas which have brown colors in the hue image and a lot of edges of random directions, and regard them as damaged areas. Figure 2 shows an overview of our method I.

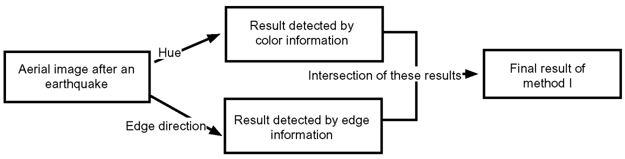


Figure 2. Overview of method I

2.1. Detection by color information

As for color information, an important point is that damaged areas usually look brown. It is the color of the ground as well as the color of lumbers, main materials of Japanese houses. Such areas are detected by thresholding the hue image with specified brown range. Furthermore, for eliminating small regions and detecting blob-like regions, we apply smoothing to the detected brown regions with a 15×15 uniform weight filter and threshold its output. The obtained regions are determined as damaged areas by color information. The range of hue specified as brown is from 33 to 45 degree in hue value 0-360 degree, and the threshold for the filter output is 50 in the experiment.

2.2. Detection by edge information

As for edge information, the distribution of edge directions is more important than edge intensities in damaged areas. In Figure 3, the right three images (b), (c), and (d) show edge directions by needles, in areas of railroad tracks, collapsed buildings, and non-collapsed buildings, respectively. In the damaged area of collapsed buildings, the edges have short lengths and random directions. On the other hand, in the non-damaged area of railroad track or buildings, the edges point to mostly one direction or the direction perpendicular to it.

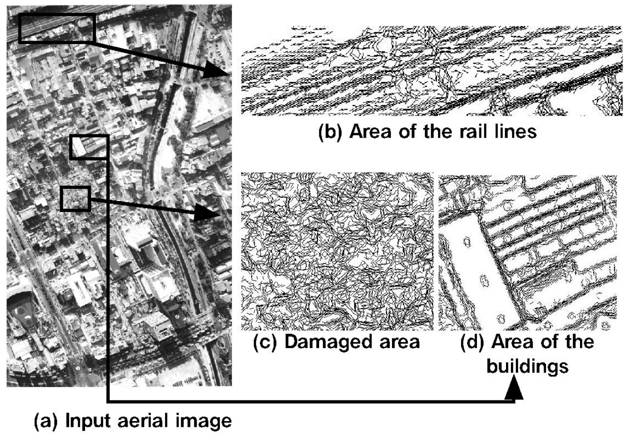
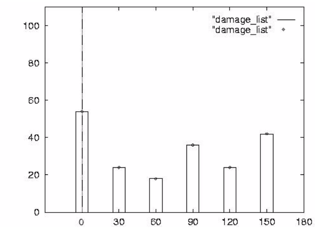


Figure 3. Edge directions shown by needles

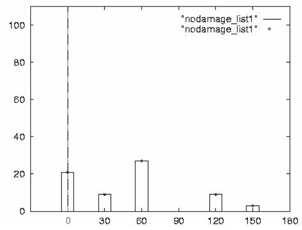
This assures us that the discrimination of damaged areas from non-damaged areas can be done by using edge direction distributions. By analyzing distributions in detail, typical histograms of edge directions in a damaged area and non-damaged areas are illustrated in Figure 4. The abscissa of histogram is edge direction from 0 to 180 degree divided into 30 degree intervals and the ordinate is frequency of edge directions. Figures (a), (b) and (c) show histograms in areas of collapsed buildings, non-collapsed buildings and railroad tracks, respectively. The histogram of a damaged area is more or less flat as in (a), because there are a lot of short edges in random directions. On the other hand, the histogram of a non-damaged area shows low frequency in total as in (b) or concentrated in one or two directions as in (c). This is because the edges are sparse or point to only a few directions in the artifacts such as buildings or railroad tracks.

Then by using the above characteristics of histogram of edge directions, we detect damaged areas as follows.

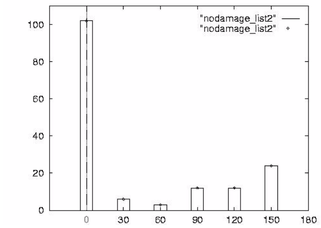
First, we apply Sobel edge detector to the lightness image of a color aerial photograph and obtain edge intensities and edge directions. The x- and y- components of the output of Sobel filter are derived from a gray-scale image f as follows.



(a)Damaged area



(b)Non-damaged area with low frequency in total



(c)Non-damaged area with unbiased frequencies

Figure 4. Typical histograms of edge directions

$$\begin{aligned}\Delta f_x(i,j) &= f(i+1,j-1)+2f(i+1,j) \\ &\quad +f(i+1,j+1)-f(i-1,j-1) \\ &\quad -2f(i-1,j)-f(i-1,j+1), \qquad (1)\\ \Delta f_y(i,j) &= f(i+1,j+1)+2f(i,j+1) \\ &\quad +f(i-1,j+1)-f(i+1,j-1) \\ &\quad -2f(i,j-1)-f(i-1,j-1). \qquad (2)\end{aligned}$$

Edge intensity and edge direction are calculated by:

$$h(i,j) = \sqrt{\Delta f_x(i,j)^2+\Delta f_y(i,j)^2}, \qquad (3)$$

$$\theta(i,j) = \arctan\left(\frac{\Delta f_x(i,j)}{\Delta f_y(i,j)}\right). \qquad (4)$$

We detect edge points by thresholding obtained edge intensities.

Next, for the detected edge points, edge direction histograms are computed in each region of 15×15 sizes. If a region has a larger number of edge points than a preset threshold (157, in the experiment) and all frequencies of its edge direction histogram are lower than another given threshold (60, in the experiment), it is extracted as a region having a lot of edges with random directions, that is, as a damaged area determined by edge information.

Finally, we make the intersection of those areas extracted by color information and edge information.

2.3. Experimantal Results

In this subsection, we illustrate experimental results of our method I and compare them to the results obtained by the method in [1]. In Figure 5, (a) shows an input aerial image of a part of Kobe city, Japan, taken just after the Hyogoken-Nanbu Earthquake. (b) is the result detected by color information, (c) is the result detected by edge information, and (d) is their intersection, that is, the final result of our method I. Black regions in each image are detected as damaged area in each process.

Figure (e) depicts a comparison of this result with the damaged areas drawn by human observation. The union of lightly shaded and hatched regions are determined as damaged areas by one of the authors. The lightly shaded regions are detected by method I correctly. The hatched regions failed to be detected. The black regions are detected by method I erroneously. Fig. (f) shows a similar comparison of the same damaged areas detected by human and the damaged area detected by the method in [1].

Comparing the results of our method I and the method in [1], the black areas, or the false alarm areas, of our method is much smaller than those of the latter method, especially in the railroad tracks at the upper left of the image, the ground at upper right, and the areas along the streets.

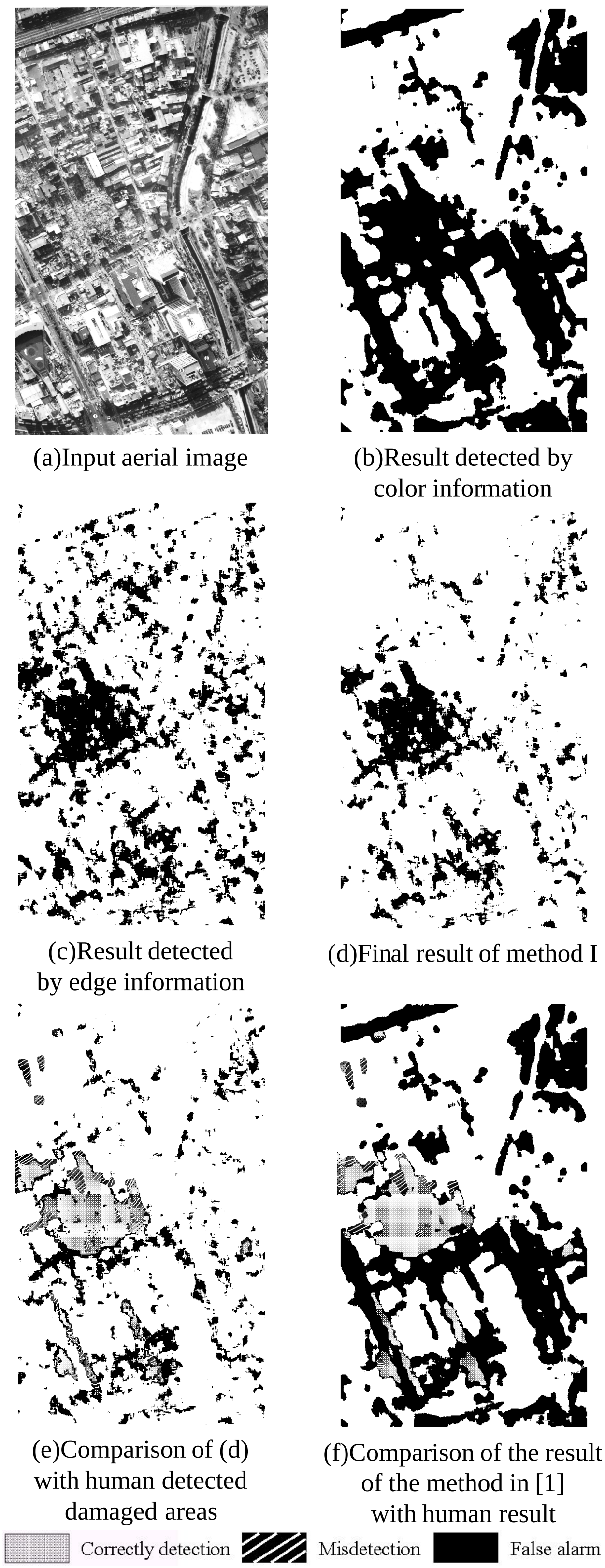
Our method has still the following problems to overcome.

- How to decrease the misdetected areas (the hatched regions)

  The main reasons of misdetection are shadow of builidings (becuase of lack of edge information) and non-brown damaged areas.

- How to decrease the false alarm areas (the black regions)

  This is due to mainly cars or people on roads or grounds (becuase of a similar color to brown and high frequencies in edge directions)



(a)Input aerial image

(b)Result detected by color information

(c)Result detected by edge information

(d)Final result of method I

(e)Comparison of (d) with human detected damaged areas

(f)Comparison of the result of the method in [1] with human result

Correctly detection Misdetection False alarm

Figure 5. Experimantal results of method I

3. Method II: Detection from aerial image pair

Next, we describe our second method which is applicable to the case that both aerial photographs of almost the same geographical area before and after the earthquake are available. In this case, we have to take into account that the two images were taken in different conditions: camera positions (horizontally and in altitude), lighting conditions (due to weather and time of the day, etc.), camera parameters, and so on. Therefore, we first match the two images by transforming geometrically and registering one image to the other, and then compare the colors of corresponding pixels in consideration of the difference of lighting conditions.

We extract the damaged areas by calculating the difference of colors of two pixels in the same geographical location. For calculating the difference, we first match the two images by using affine transformation. Then, we judge whether the colors of each matched pixel pair can be regarded as the same in consideration of the difference of lighting conditions. In the color difference calculation, we use hue, lightness, and saturation of each pixel. Finally, we extract the damaged areas by classifying the difference of colors.

3.1. Affine transformation

It is not reasonable to assume that the two aerial images are taken at the same viewpoint and angle, and hence, we first match the two images. In this study we use affine transformation to register one image to the other. First, we extract the feature points to be matched from the two images by hand. The corners of buildings are selected as the feature points in our experiments. The number of the points should be more than three. Next, we compute affine parameters (a, b, c, d, e, f) from the coordinates of the feature points on the two images by using the equations:

$$\begin{aligned} x_2 &= a_1 + by_1 + c. \\ y_2 &= dx_1 + ey_1 + f. \end{aligned} \quad (5)$$

where, (x_1, y_1) and (x_2, y_2) are the coordinates of the feature points in the two images taken before the earthquake and after the earthquake, respectively. If the pairs of feature points are selected more than three, these parameters are determined in the minimum square error criterion. Finally, we match the whole regions of the two images from the above six parameters.

3.2. Calculation of color differences

It is difficult to determine whether a shadow region in the image is a damaged area or non-damaged area by using only the color values. The lightness of the shadow area is rather low and difficult to compare the colors. In this study we defined an area of lightness lower than a threshold as undetermined area. We can determine whether an area of high lightness is a damaged area or a non-damaged area by using hue and saturation. However, it is difficult to determine whether a region of low saturation is a damaged area or a non-damaged area by using only hue. In the color difference calculation, we select hue or saturation as the operands of comparison, and the selection depends on the classification of the matched two pixels as follows: Now, let H_b, L_b, and S_b be hue, lightness, and saturation of a pixel of the before earthquake image, and H_a, L_a, and S_a be hue, lightness, and saturation of a pixel of the after earthquake image. T_b, T_a, T_L, and T_H are the thresholds and determined by a preliminary experiment.

- Case 1. $(S_b < T_b \quad and \quad S_a < T_a)$: both low saturation

  If $|L_a - L_b| \geq T_L$, then the pixel is in the damaged area.

  Otherwise, the pixel is in the non-damaged area.

- Case 2. $(S_b \geq T_b \quad and \quad S_a \geq T_a)$: both high saturation

  If $|H_a - H_b| \geq T_H$, then the pixel is in the damaged area.

  Otherwise, the pixel is in the non-damaged area.

- Case 3. $(S_b < T_b \quad and \quad S_a \geq T_a) \quad or \quad (S_b \geq T_b \quad and \quad S_a < T_a)$: one in low saturation, the other high

  If $|H_a - H_b| \geq T_H \quad and \quad |L_a - L_b| \geq T_L$, then the pixel is in the damaged area.

  If $|H_a - H_b| < T_H \quad and \quad |L_a - L_b| < T_L$, then the pixel is in the non-damaged area.

  Otherwise the pixel is in the undetermined area.

3.3. Experimantal Results

We use two aerial images of Kobe city. One image is taken 100 days after the Hyogoken-Nanbu Earthquake, and the other is taken 5 years after the earthquake. We used the latter as the image before the earthquake. The size of each image is 920×690 pixels. Figures 6 and 7 show the two images after affine transformation. We calculate the difference of two color values of each pixel pair of two images. Then, we classify the pixels into three areas (damaged, non-damaged, and undetermined) from the color difference as described above. In Figure 8, damaged areas, non-damaged areas, and undetermined areas are shown in black, white, and gray, respectively. After labeling the connected components of the damaged areas, we extract only the damaged areas whose size is more than 450 pixels. The final result is shown in Figure 9 as the areas surrounded by the white rectangles. As shown in the figure, the extracted areas by our method II are correctly the areas where the houses are collapsed. Most of the undetermined areas are the shadow regions and cannot be classified only by using the color values. The analysis of the shadow regions (undetermined areas) is a future work. For analyzing those areas, we may have to use not only the pixel color values but also the boundary shapes of the houses and roads.

Figure 6. 100 days after the Hyogoken-Nanbu Earthquake

Figure 7. 5 years after the Hyogoken-Nanbu Earthquake

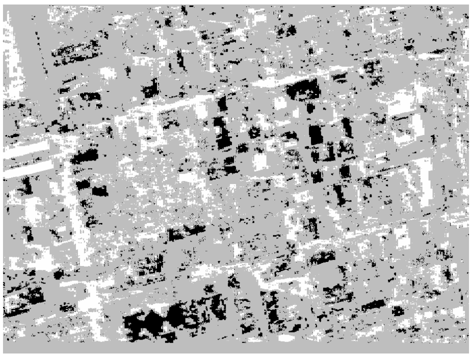


Figure 8. Classification of pixels

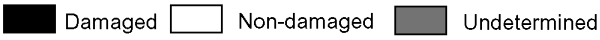


Figure 9. Detection of damaged areas by method II overdrawn on Figure 6

4. Conclusion

We proposed two methods of detecting the damaged areas by an earthquake, depending on whether an aerial image before the earthquake is available or not. From the experimental results we confirmed the effectiveness of utilization of color aerial images for detecting damaged areas such as collapsed buildings. In the first method we assumed the damaged areas look brown. Because some damaged areas do not satisfy this condition, we have to reconsider the assumption. Besides, both methods have common shortcomings to be improved in future. Judgement of damages in shadow regions is one problem, and automation of setting threshold and parameter values is another. Other future works to be done are how to combine with map information for eliminating the false alarm areas such as grounds and roads, and how to display the detected damaged areas on the map effectively.

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