DETECTION OF COLLAPSED BUIDINGS DUE TO EATHQUAKE IN URBAN AREAS

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ABSTRACT:

As the initial investigation on disaster occurrence, it is very important for reducing economical losses to obtain timely observation of damages especially in metropolis. In such situation, information on changed area obtained from aerial photo analysis is promising.
In this study, we propose a change detection approach objected for metropolis right after the disaster with automatic image processing of aerial photos. We introduce two different types of approaches. The first method is for the case of no available orientation information. In this case change detection is performed by registration of images, which are taken before and after the disaster. We define this approach as 2D image matching method. The second approach aims at acquiring not only 2D changes' distribution but also quantitative 3D shifts by matching between digital terrain data and images before and after the disaster. We call this approach 3D image matching method.
In the first step of 2D image matching method, initial registration is executed for minimizing the matching process between images before and after disaster. This process is performed automatically by detecting appropriate conjugate points which candidates are derived from images independently with the improved relaxation method and a mathematical model, which is constrained by a photogrammetric principle (relative orientation). In the next step, image rectification is executed. Owing to these processes y-parallax in images is eliminated and matching process is restricted in x-axis. In the case of relative orientation failure, formation of imaginary stereo model by perspective projection is executed as a substitutive means. For detecting changed area, the adaptive nonlinear mapping is applied. This method is based on model of self-organization in neural network. The one of the image pair is mapped to the other by iterative local deformation. Changed areas are detected as inconsistent matching in the mapping process.
On the other hand, the concept of 3D image matching method is to compare not only changed images but also the additional terrain information created before disaster. In this case, it is assumed that stereoscopic aerial photos and exterior orientation are available. Former digital terrain data such as DSM or digital maps is transformed based on exterior orientation parameters and 3D matching is carried out. Changed areas are detected as inconsistent texture or height anomaly.
Evaluation tests were performed with actual aerial photos that were taken right after of the earthquake and several years later respectively. To evaluate the ability of change detection, the results are compared with those by human interpretation. For quantitative estimation, ROC (Receiver Operating Characteristic) chart was applied, which plots sequential probability of detection against probability of false alarm. As a result, 80 % of right change detection was achieved when false alarms were about 30 % in 2D image matching method and 18 % in 3D image matching method respectively.

1. INTRODUCTION

As the initial investigation on disaster occurrence, it is very important for reducing economical losses to obtain timely observation of damages especially in metropolis. In such situation, information on changed area obtained from aerial photo analysis is promising. We have conducted a study on automatic change detection of disaster area by earthquakes as a part of the national project entitled Special Project for Earthquake Disaster Mitigation in Urban Area. The purpose of our team is to establish the technique of prompt and efficient collection of changed or collapsed area in the early stage of earthquake occurrence, through automatic change detection with aerial imageries taken before and after the earthquake.
In this study, we propose two different types of change detection approaches. The first one is for the case of no available orientation information for aerial imageries. In this case change detection is performed by registering images taken before and after of the disaster. We define this approach as 2D image matching method. The second approach aims at acquiring not only 2-dimensional changes' distribution but also quantitative 3-dimensional shifts by matching digital terrain data (vector map data) and stereo images before and after the disaster. We call this approach 3D matching method.
In the 2D image matching method, imaginary stereo model is formed for minimizing and stabilizing the image registration process before and after the disaster. For detecting changed area, adaptive nonlinear mapping is applied. It is based on the model of self-organization in neural network (Kosugi et al., 2000, 2001a, 2001b; Sakamoto et al., 2001). The one of the image pair is mapped to the other by iterative local deformation. Changed areas are detected as inconsistent matching in mapping process.
On the other hand, the concept of 3D image matching method is to compare not only changed images but also the additional terrain information, which is managed and created before

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disaster in local government. In this case, it is assumed that stereoscopic aerial photos and exterior orientation are available by GPS/IMU. Former digital terrain data such as DSM or digital maps is transformed based on exterior orientation parameters and 3D matching. Changed areas are detected as inconsistent texture or height anomaly.
Evaluation tests were performed with actual aerial photos that were taken right after of the earthquake and several years later.

2. CONCEPT AND STATISTICS

This study is objected for timely observation of area damaged by earthquake, especially for buildings, by establishing automatic change detection system. Automatic change detection system is needed for a disaster area in its early stage because such information is demanded for planning rescue mission or limiting the expansion of the damage. Fig.1 shows the flow of urgent correspondence system for a huge earthquake occurrence, which is the target of this study. In this system, there are two typical cases of change detection approaches. The first one is a direct comparison method and the other one is an indirect comparison method respectively.
The assumptions for the two approaches are as follows.

(1) For direct comparison method
1) No orientation parameters for aerial photos before and after the earthquake are available except approximate geographic coordinate.

(2) For indirect comparison method
1) Stereo pairs of aerial imageries before and after the earthquake are available.
2) Internal and external orientation parameters are known.
3) 2D or 2.5D digital map data for buildings of target area are prepared in local government's spatiotemporal GIS (Geographic Information System) data server and are available for the change detection process.

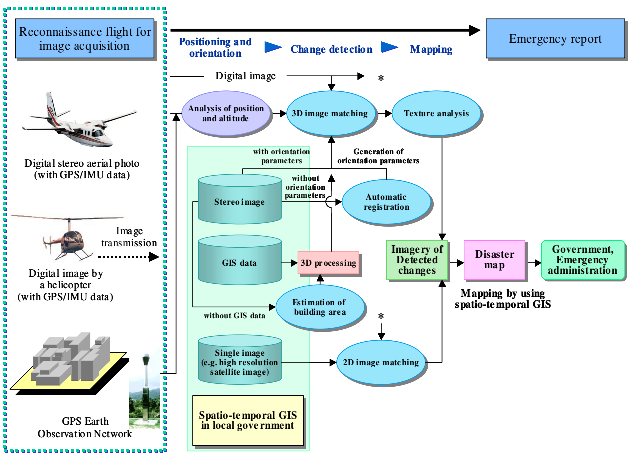


Figure 1. Urgent correspondence system for a huge earthquake occurrence

External orientation parameters are obtained by on flight analysis of GPS/IMU.
In the first approach, we can use only single aerial imagery before and after the earthquake for the target area, which also means that no stereo pairs are available and 3D information is not acquired. In this case, change detection is executed by 2D comparison of images. We call this approach 2D image matching method and this process is realized with a unique registration method called adaptive nonlinear mapping in this study.
On the other hand, indirect comparison method utilizes stereo pair imageries and orientation parameters in addition to digital map data. The changes of disaster area are detected as 3D shift.

3. CHANGE DETECTION BY 2D IMAGE MATCHING METHOD

3.1 Process Flow

Fig.2 shows the process flow of 2D image matching method. In the first step, a pair of aerial imageries before and after the change is used to form an imaginary stereo model, which is objected for facilitating and stabilizing image matching process. In the next step, image matching is carried out. Geometrical registration processes such as affine transformation or Helmert's transformation are not applicable or sufficient for this process due to the influence of parallax. To solve this problem, adaptive nonlinear mapping method is applied in this study. In the last step, change area is detected as the inconsistent area of adaptive nonlinear mapping. The details of the processes are described in the following sections.

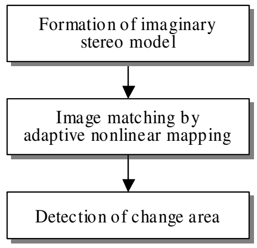


Figure 2. Process flow of 2D image matching method

3.2 Formation of Imaginary Stereo Model

Formation of imaginary stereo model is for reducing calculation time and increasing the stability of adaptive nonlinear mapping process. Fig.3 shows the processing flow for formation of imaginary stereo model. In the first step, pre-processing is conducted such as contrast adjustment by automatic process or adjustment of image resolution by manual process and so on. The next step detects matching points in a pair of images taken at different time. Either automatic or manual process is performed by the judgement of operator. The automatic detection realizes automatic detection of pass points with high accuracy from stereo model (Sakamoto et al., 1998). The principle is based on point matching with improved relaxation method and a mathematical model. If the automatic process fails to detect matching points, manual detection by operator is performed.
In the next step, relative orientation parameters are calculated with matching points detected above. If the calculation is successful, formation of stereo model by image rectification is followed. Different from normal stereo model of aerial images, some case has been confirmed that the adequate stereo model cannot be generated since the difference of the altitude of photographing sites in two images. In this case formation of stereo model by perspective projection is applied instead of image rectification.
Image rectification is based on epipolar geometry, which reduces the direction of mapping (matching) to x-direction only.

Photographic coordinate uv is 2-dimensional, with the origin at the camera's principal points of a stereo model (Fig.4). Model coordinate is xyz 3-dimensional, with the origin at the center of projection O_1 and parallel to uv. Here we set the center of projection O_2 as position $(1, b_y, b_z)$ with rotation $(\varpi, \varphi, \kappa)$, focal length of cameras as f_1 and f_2 respectively. Then model coordinates of ground point P are observed at O_1 and O_2 as follows in photographic coordinate.

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} u_1 \\ v_1 \\ -f_1 \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varpi & -\sin\varpi \\ 0 & \sin\varpi & \cos\varpi \end{bmatrix} \begin{bmatrix} \cos\varphi & 0 & \sin\varphi \\ 0 & 1 & 0 \\ -\sin\varphi & 0 & \cos\varphi \end{bmatrix} \cdot \begin{bmatrix} \cos\kappa & -\sin\kappa & 0 \\ \sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_2 \\ v_2 \\ -f_2 \end{bmatrix} + \begin{bmatrix} 1 \\ b_y \\ b_z \end{bmatrix} \tag{2}$$

Then projective transformation of the images is as follows.

$$\begin{bmatrix} u_1' \\ v_1' \end{bmatrix} = \begin{bmatrix} x_1 \\ y_1 \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} u_2' \\ v_2' \end{bmatrix} = \frac{f_1}{(z_2 - b_z)} \begin{bmatrix} x_2 - 1 \\ y_2 - b_y \end{bmatrix} \tag{4}$$

According to the above image rectification process, each epipolar lines are realigned so as to be parallel to x-direction. On the other hand, perspective projection is performed with the following equations.

$$X = \frac{a_1 x + a_2 y + a_3}{a_7 x + a_8 y + 1} \qquad Y = \frac{a_4 x + a_5 y + a_6}{a_7 x + a_8 y + 1} \tag{5}$$

where x, y = a coordinate at the image of one side
X, Y = a corresponding coordinate for (x, y) at the image of another side
a_1 - a_8 = transformation coefficients

Transformation coefficients are calculated by the least squares method with matching points.

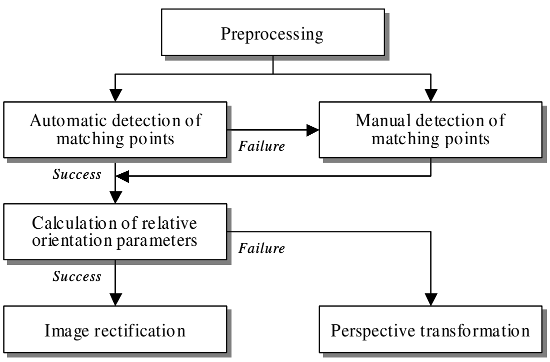


Figure 3. Process flow for formation of imaginary stereo model

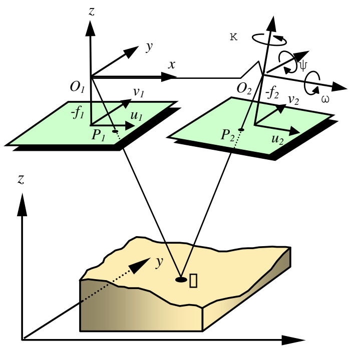


Figure 4. Coordinate system in a stereo model

3.3 Principle of Adaptive Nonlinear Mapping

Adaptive nonlinear mapping is based on Coincident Enhancement principle that is an extended Hebbian rule for self-organization in neural network model. This model has a feedback process that is consisted of control mechanism called competition process and consensus process, as shown in Fig.5. This concept can be applied to image registration process.

(1) Competition process
Now we consider a pair of stereo model, which consists of image A (input layer) and image B (output layer). We define the position of local sub-area in these images as $\mathbf{x}_{ij}$, $\mathbf{y}_{ij}$ using grid number (i, j) respectively, the evaluation value of these area as f($\mathbf{x}$), g($\mathbf{y}$), and the iterative process number as k. Then the difference type of similarity function is defined as Eq.6.

$$F(\mathbf{x}_{ij}^k) = \left\| f(\mathbf{x}_{ij}^k + \mathbf{d}_{ij}^k) - g(\mathbf{y}_{ij}^k) \right\| \tag{6}$$

$$\left\| \mathbf{d}_{ij}^k \right\| < \boldsymbol{\theta}^k,\ \boldsymbol{\theta}^k = (\Delta x^k, \Delta y^k),\ \Delta x^k, \Delta y^k > 0 \tag{7}$$

where $\mathbf{d}_{ij}$ = a mapping (shift vector) from $\mathbf{x}_{ij}$ to $\mathbf{y}_{ij}$,
$\boldsymbol{\theta}^k$ = a vector which limits the search area in the competition process
$\Delta x, \Delta y$ = positive constants

Several evaluation values including pixel brightness or other sophisticated features are taken as the sum of feature vectors. Competitive shift vectors are formed by searching for the optimum position where evaluation function by Eq.6 is minimized according to Eq.8 in each sub-area.

$$e_{ij}^k = \min(F(\mathbf{x}_{ij}^k)) \tag{8}$$

where e_{ij}^k = the error of evaluation value at the position where the error reaches minimum
min() = a function which returns minimum value

(2) Consensus process
Conceptually, the consensus process is executed for maximizing mutual information. Concretely, this process is introduced for adjusting inconsistent shift vectors generated in competition process by taking into account of mutual relationship of shift vectors. There are some models to realize such a process, and we have adopted a model that emphasizes the shift's continuity of mapping. This process is realized by selecting the median

shift vector from those in the consensus area **R** that has arbitrary shape and size around the target position.

$$\mathbf{d}_{ij}^{k+1} \leftarrow median\left(\mathbf{d}_{ij}^{k} \in \mathbf{R}\right) \tag{9}$$

where median() = a function which returns median value

(3) Feedback process
The convergent characteristics of mapping varies due to not only the evaluation value but also the size of sub-area, shape and size of consensus area and so on. After several competition and consensus process, these parameters are updated and these processes are repeated. Feedback process is terminated when all shifts in mapping are below a predefined value or the iteration number of process reaches the preset one.

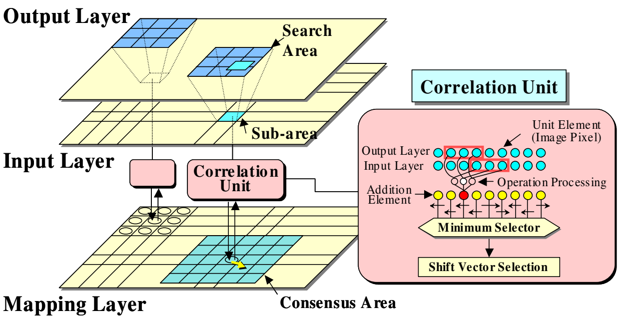


Figure 5. Conceptual diagram for adaptive nonlinear mapping

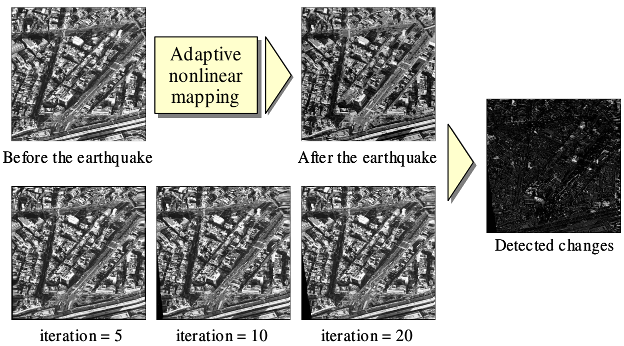


Figure 6. Change detection by adaptive nonlinear mapping

3.4 Evaluation of Change Detection Ability by ROC

For evaluating of the automatic change detection ability, we use ROC (Receiver Operating Characteristic) chart, which has been widely used in evaluating the performance of radar and sonar systems (Vantree, 1968). For our application, we redefined the equations as follows.

$$\begin{aligned} PD &= Nr/Nc \\ PF &= Nf/(Nt - Nc) \\ Nf &= Na - Nr \end{aligned} \tag{10}$$

where PD = Probability of detection
PF = Probability of false alarm
Nr = Number of buildings which are correctly detected of the changes
Nc = Number of buildings which are actually changed
Nf = Number of buildings which are incorrectly detected of the changes
Nt = Number of targeted buildings
Na = Number of buildings which are automatically detected as the changed buildings

As in general, when we adjust the threshold level that specifies the changed and non-changed area separately so as to get higher PD value, at the same time the ratio of false change detection increase, which means higher PF. Therefore when we plot the ROC chart with PF value as x-axis and PD as y-axis, an ideal curve should rise rapidly in upper left direction.
The number of buildings is used when vector maps of buildings are available. However when digital maps are not available in 2D image matching method, pixel number is used for the evaluation.

4. CHANGE DETECTION BY 3D IMAGE MATCHING METHOD

4.1 Process Flow

The flow of 3D image matching is shown in Fig.7. In this approach, we assume that stereo models with exterior orientation before and after the earthquake and latest digital map data managed by national or local government are available. In the first step, matching between buildings in digital map and stereo models is executed. If the digital map is 2D, each altitude of building will be calculated by supposing that all nodes of the polygon have the same height, making all polygons of buildings 2.5D. This process is conducted by matching raster image and vector data with consideration of geometric constraint based on exterior orientation parameter. Namely under the condition that x-y coordinates of a polygon building is fixed, z coordinate (altitude) is gradually shifted and projected photo coordinate as raster image for evaluating matching criterion in each supposed z value. Finally the most suitable height is selected where the best matching criterion is given. The cross correlation coefficient is used as evaluation function in this study. In the same way, z-direction polygon matching is executed in both stereo models before and after the earthquake.
If there are changed areas in the image after earthquake, inconsistency of altitude between stereo models will occur. Therefore change detection by z-difference is performed in the next step.
The decision of whether a building has changed or not is carried out by the following judgement.

$$\begin{aligned} &\left|Z_{before} - Z_{after}\right| > Z_{thres} : \quad changed \\ &others : \quad not\ changed \end{aligned} \tag{11}$$

where Z_{before} = Estimated altitude of building in before earthquqke
Z_{after} = Estimated altitude of building in after earthquqke
Z_{thres} = Threshold of altitude difference

In the next step, decision of change detection by texture analysis is carried out so as to solve the case that change has occurred with minor height change. The following image texture indexes are applied in this study. Indexes show “constant (C)”, “angular second moment (A)”, “entropy (E)” and “mean (M)” respectively (Weszka et al., 1976).

$$C=\sum_{k=0}^{n-1}k^2P_\delta(k), \qquad A=\sum_{k=0}^{n-1}\{P_\delta(k)\}^2 \tag{12}$$

$$E=-\sum_{k=0}^{n-1}P_\delta(k)\cdot\log\{P_\delta(k)\}, \quad M=\sum_{k=0}^{n-1}k\cdot P_\delta(k)$$

where $\delta =$ Shift (distance) from the target point
k = Brightness difference compared to target point
$P_\delta(k)$ = Occurrence probability of the pixel where k is brightness difference and δ shift

These indexes are combined linearly for the evaluation function and the coefficients for the indexes are determined by supervised learning in other experiments.

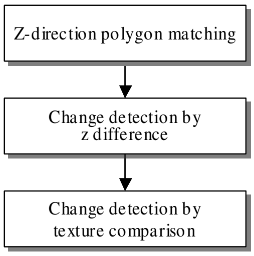


Figure 7. Process flow of 3D image matching method

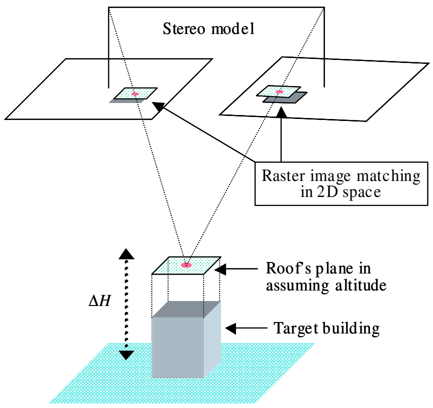


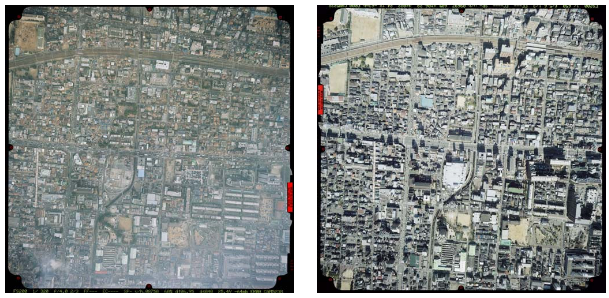
Figure 8. Process flow of indirect comparison method

5. EXPERIMENTS

Evaluation tests were performed with actual aerial photos that have been taken right after of the earthquake (1995) and 8 years later (2003). The scale of photo is 1/4000 and the image size is 20000 by 20000 respectively.

Fig.10 shows an imaginary stereo model by perspective projection with automatically detected matching points. Fig.11 shows the result of adaptive nonlinear mapping in 2D image matching method in the case of mapping from Fig.10 (b) to Fig.10 (a) and the result of change detection. It was ascertained that correct deformation was achieved if increase the iteration.

The photo interpretation result by human operator for evaluating change detection ability is shown in Fig.12. Fig.13 is a change detection result by 3D image matching method. For quantitative estimation ROC chart was applied, which plots the sequential probability of detection against the probability of false alarm. Fig.14 (a) shows the chart in which x axis is the change of building's height and y axis is the change detection ratio or false alarm in the case of 3D image matching method. Similarly, Fig.14 (b) shows ROC chart. As a result, 80 % of right change detection has been achieved when false alarms are about 30 % in 2D and 18 % in 3D image matching method respectively.

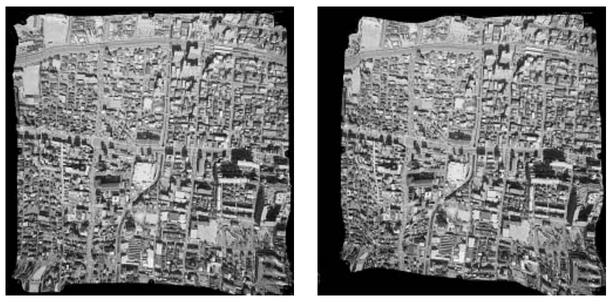


(a) Right after the earthquake (b) 8 years later the earthquake

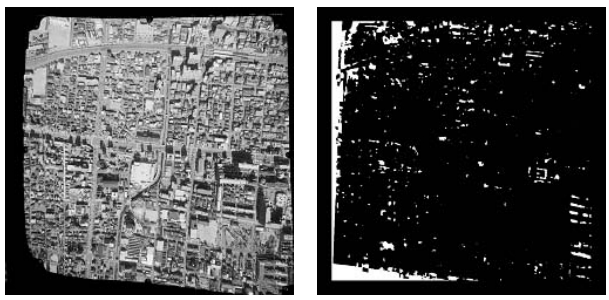
Figure 9. Aerial images for experiment

(a) Perspective projection of Fig.9 (a) (b) Same with Fig.9 (b)

Figure 10. Imaginary stereo model (greyscale image)



(a) Mapping process (iteration = 1) (b) Mapping process (iteration = 5)

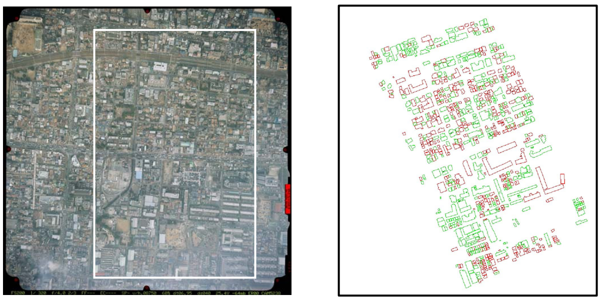


(c) Mapping process (iteration = 20) (d) Change detection result (binary image)

Figure 11. Change detection by 2D image matching method

As regards texture analysis, change detection showed the best result when coefficients of the indexes are 3.0 - 9.0 for contrast,

0.5 - 1.5 for angular second moment, 0.0 for entropy and 0.0 - 1.0 for mean by some supervised learning experiments.
Another experimental result for change detection between aerial photos in 1998 and 2003 shows 80% of right change detection can be achieved when false alarms are about 6% in 3D image matching method (Fig.15). The result of Fig.14 is poor compared to this result. This is probably caused by long passage years of the image to be compared and the influence of clouds that are visible in Fig.9 (a).



(a) Target area of photo interpretation

(b) Photo interpretation result (green: not changed, red: changed)

Figure 12. Photo interpretation result

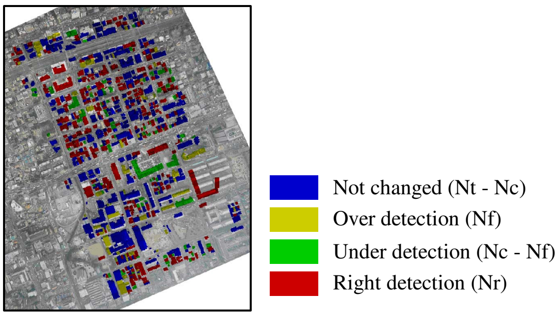


Figure 13. Change detection by 3D image matching method

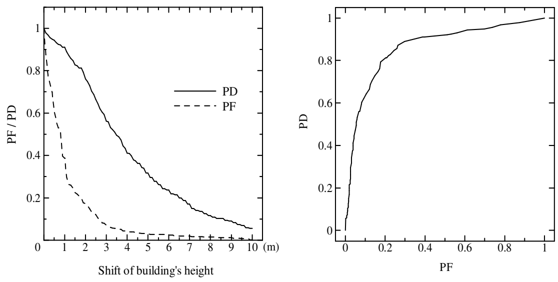


Figure 14. Change detection ability by 3D image matching method (1995 - 2003)

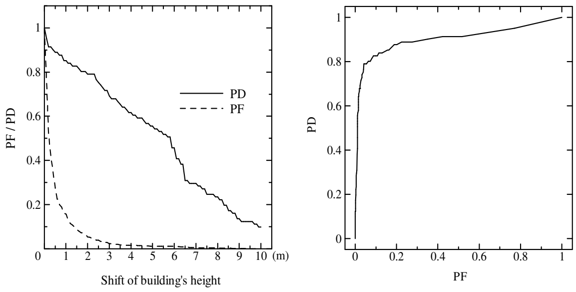


Figure 15. Change detection ability by 3D image matching method (1998 - 2003)

6. CONCLUSIONS

In this study, we proposed a change detection approach objected for metropolis right after the disaster with automatic image processing of aerial imageries. We introduced two different types of approaches that are 2D image matching method and 3D image matching method. The first method is for the case when no orientation information is available. The second approach aims at acquiring not only 2-dimensional changes' distribution but also quantitative 3-dimensional shifts by matching between former digital terrain data and images after the disaster.
Evaluation tests were performed with actual aerial imageries that were taken right after the earthquake and several years later. To evaluate change detection ability, comparison of change detection results with photo interpretation by human operator is utilized. For quantitative estimation ROC chart was applied, which plots the sequential probability of detection against the probability of false alarm. As a result, 80 % of right change detection has been achieved when false alarms are about 30 % in 2D image matching method and 18 % in 3D image matching method respectively.

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