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# AUTOMATIC DETECTION OF BUILDING PROPERTIES FROM AERIAL PHOTOGRAPHS USING COLOR AND 3D CONFIGURATION

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**ABSTRACT:** The buildings properties in spatial databases are very useful for urban planning, disaster mitigation, insurance business etc. But the databases in some governments are not freely available since they include private information. Therefore, the data acquisition mostly depends on image interpretation of photographs and field surveys. Consequently it is time- and labor-consuming and very costly to construct databases, and it is not easy to maintain the data up-to-date and to employ them in wide use. In this study, automatic detection method of building properties based on aerial photographs is proposed and the result is verified by the database made in a conventional way of data acquisition. The method consists of the following steps: (1) geometric correction and gray scale conversion of aerial photographs, (2) stereo matching and evaluation of building heights, (3) evaluation of building areas, (4) color and texture analysis, and (5) classification of buildings. Buildings are classified into the following categories: (a) detached houses, apartment buildings and multi-storied buildings. (b) wooden and non-wooden buildings. The method is applied for a target area in Tokyo and the result is compared with the ground truth data investigated by the authors and the database provided by of Tokyo Metropolitan Government. As a result, it is found that low-storied apartment buildings and multi-storied buildings are correctly identified and they can be classified into proper structural types.

## 1. INTRODUCTION

Spatial databases which include properties of individual buildings are very useful for analyses of various fields such as urban planning, disaster mitigation planning, insurance business and so on. Though such databases are stored as official data in some countries, they are not available outside the government since they include private information. Therefore the data acquisition mostly depends on image interpretation of photographs and field surveys. The problem is that it is time- and labor-consuming and very costly to construct such databases, and hence it is not easy to maintain the data up-to-date and to employ them in wide use.

In this study, the automatic detection method of building properties based on aerial photographs is proposed to address this problem. The method is applied for a target area and the result is evaluated by an actual database which has been made in a conventional way of data acquisition.

## 2. METHOD OF BUILDING PROPERTIES DETECTION

### 2.1 Analysis Flow

The flows of the analysis are shown in Figure 1. First, aerial photographs are digitized and preprocessed to remove noise. Geometric correction and gray scale conversion are conducted for the digitized aerial photographs. After that, there are two streams in the flow. One is color and texture analysis and the other is 3D based on stereo matching. Finally buildings are classified based on these analysis results, and the GIS database of the evaluated building properties is developed.

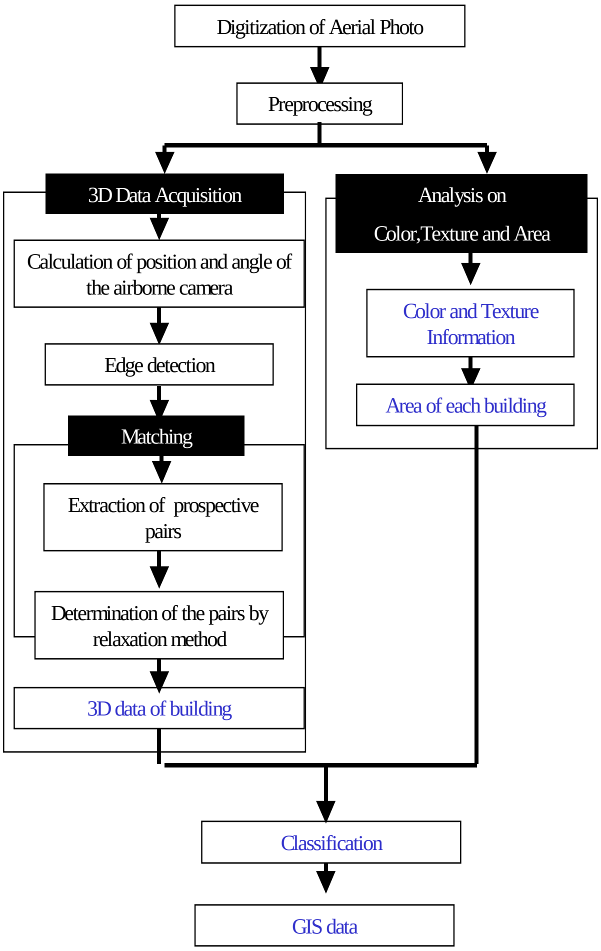


Figure 1 Flow of building property detection

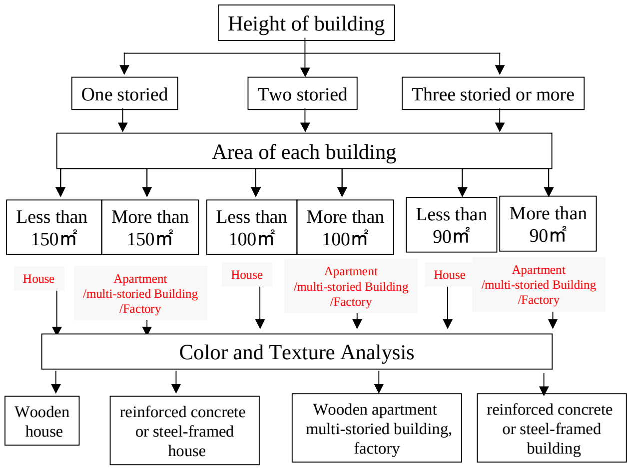


Figure 2 Flow of building classification

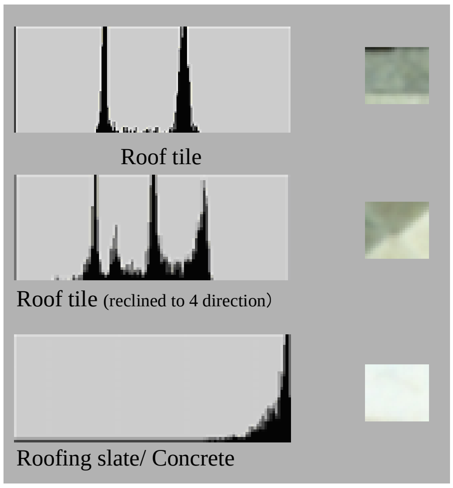


Figure 3 Brightness histograms of typical roofs

With respect to the building properties, the following items are considered. The number of stories is estimated based on the building height evaluated by stereo matching. Based on their heights, the buildings are firstly categorized into two groups: one or two-storied houses, apartment buildings, and multi-storied reinforced concrete or steel-framed buildings. Based on the result of color and texture analysis and the evaluated building area, the buildings are classified into three groups: detached houses, apartment buildings and multi-storied buildings. In addition, these buildings are also classified into two categories: wooden and non-wooden buildings with regard to the structural type. The flow of building classification is shown in Figure 2.

### 2.2 Color and Texture Analysis

The color images of digitized aerial photographs are converted from RGB (red, green, and blue) coordinate to HSI (hue, saturation, and intensity) coordinate in order to remove influence of shade and shadow. The continuous area which has almost the same color is considered as one building. Then the histogram of intensity is calculated to examine the roof texture of each building. The roof of each building is classified into three classes with the maximum likelihood classification (Muerle, 1970) based on the typical roof cover histograms as shown in Figure 3.

### 2.3 Stereo Matching

Stereo matching is a method to create the 3D model by calculating the parallax between the corresponding points in more than 2 images (Murai, 1983). Therefore each object must be automatically recognized as itself in two or more images by a computer. The first step of stereo matching is to determine the corresponding points in multiple images. Then the 3D configuration can be calculated based on the evaluated relative orientations using coplanarity condition.

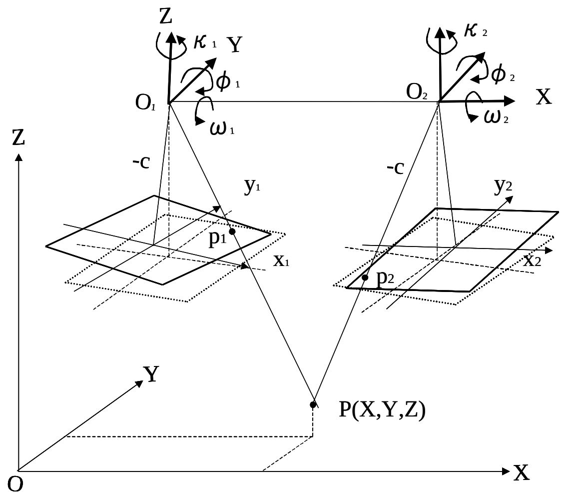


Figure 4 Model coordinates

**2.3.1 Template Matching:** In this study, template matching method is applied to the images in order to find the corresponding pair points because those images have little distortion and the target area is near the centers of the both aerial photographs. The normalized density of the images are processed by the Sobel filter to detect edges. Then a 9×9 area surrounding each pixel in an image is compared with a 9×9 area in the other image to determine which pair is the most probable to show the same point.

**2.3.2 Relative Orientation:** Coplanarity condition means that two centers of projection and the two images of a target point $P(X,Y,Z)$ must be on the same plane. As shown in Figure 4, hereby two centers of projection is denoted by $O_1(X_{01},Y_{01},Z_{01})$ and $O_2(X_{02},Y_{02},Z_{02})$, and the two images of a target point is denoted by $P_1(X_1,Y_1,Z_1)$ and $P_2(X_2,Y_2,Z_2)$, respectively. When the origin of the model space is set to $O_1$, the line connecting $O_1$ and $O_2$ is assumed as the x axis, and the length between $O_1$ and $O_2$ is taken as the unit length, the orientation parameters number only 5, two rotation angle of the left image and three rotation angle of the right image.

The coplanarity coordination can be written in the following equations using this model coordinate:

$$\begin{pmatrix} X_1 \\ Y_1 \\ Z_1 \end{pmatrix} = \begin{pmatrix} \cos\phi_1 & 0 & \sin\phi_1 \\ 0 & 1 & 0 \\ -\sin\phi_1 & 0 & \cos\phi_1 \end{pmatrix} \begin{pmatrix} \cos\kappa_1 & -\sin\kappa_1 & 0 \\ \sin\kappa_1 & \cos\kappa_1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \\ -c \end{pmatrix} \tag{1}$$

$$\begin{pmatrix} X_2 \\ Y_2 \\ Z_2 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\omega_2 & -\sin\omega_2 \\ 0 & \sin\omega_2 & \cos\omega_2 \end{pmatrix} \begin{pmatrix} \cos\varphi_2 & 0 & \sin\varphi_2 \\ 0 & 1 & 0 \\ -\sin\varphi_2 & 0 & \cos\varphi_2 \end{pmatrix} \begin{pmatrix} \cos\kappa_2 & -\sin\kappa_2 & 0 \\ \sin\kappa_2 & \cos\kappa_2 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_2 \\ y_2 \\ -c \end{pmatrix} + \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \tag{2}$$

$$\begin{aligned} &F(\kappa_1,\varphi_1,\kappa_2,\varphi_2,\omega_2) \cong \\ &F(\kappa_1°,\varphi_1°,\kappa_2°,\varphi_2°,\omega_2°) + \frac{\partial F}{\partial \kappa_1}\Delta\kappa_1 + \frac{\partial F}{\partial \varphi_1}\Delta\varphi + \frac{\partial F}{\partial \kappa_2}\Delta\kappa_2 + \frac{\partial F}{\partial \varphi_2}\Delta\varphi_2 + \frac{\partial F}{\partial \omega_2}\Delta\omega_2 = 0 \end{aligned} \tag{3}$$

$$\begin{vmatrix} x_1 & 0 \\ Y_2 & Z_2 \end{vmatrix}\Delta\kappa_1 + \begin{vmatrix} 0 & -X_1 \\ Y_2 & Z_2 \end{vmatrix}\Delta\varphi_1 + \begin{vmatrix} Y_1 & Z_1 \\ x_2 & 0 \end{vmatrix}\Delta\kappa_2 + \begin{vmatrix} Y_1 & Z_1 \\ 0 & -X_2 \end{vmatrix}\Delta\varphi_2 + \begin{vmatrix} Y_1 & Z_1 \\ -Z_2 & Y_2 \end{vmatrix}\Delta\omega_2 + \begin{vmatrix} Y_1 & Z_1 \\ Y_2 & Z_2 \end{vmatrix} = 0. \tag{4}$$

The solution of successive approximation for the equation (4) gives the orientation parameter.

Figure 5 Aerial photograph of study area

**2.3.3 Model Coordinates:** The model coordinate ($X_m$, $Y_m$ ,$Z_m$) is calculated by the following equations (5), (6) and (7):

$$X_m = t_1(X_1 - X_{01}) + X_{01} + t_2(X_2 - X_{02}) + X_{02} \quad (5)$$

$$Y_m = \tfrac{1}{2}\{t_1(Y_1 - Y_{01}) + Y_{01} + t_2(Y_2 - Y_{02}) + Y_{02}\} \quad (6)$$

$$Z_m = t_1(Z_1 - Z_{01}) + Z_{01} + t_2(Z_2 - Z_{02}) + Z_{02} \quad (7)$$

under the condition of

$$t_1 = \frac{\begin{vmatrix} X_{02} - X_{01} & Z_{02} - Z_{01} \\ X_2 - X_{02} & Z_2 - Z_{02} \end{vmatrix}}{\begin{vmatrix} X_1 - X_{01} & Z_1 - Z_{01} \\ X_2 - X_{02} & Z_2 - Z_{02} \end{vmatrix}} \text{ and } t_2 = \frac{\begin{vmatrix} X_{02} - X_{01} & Z_{02} - Z_{01} \\ X_1 - X_{01} & Z_1 - Z_{01} \end{vmatrix}}{\begin{vmatrix} X_1 - X_{01} & Z_1 - Z_{01} \\ X_2 - X_{02} & Z_2 - Z_{02} \end{vmatrix}}. \quad (8)$$

## 2.4 Classification

The buildings are classified into detached houses or the other types of buildings based on the heights and the areas of the buildings. Then using the texture information, the buildings are categorized into four groups: (1) wooden house, (2) reinforced concrete or steel-framed house, (3) wooden apartment or multi-storied building or factory, and (4) reinforced concrete or steel-framed apartment or multi-storied building or factory. The criteria of classification are decided by the repeated experiments.

# 3. VALIDITY STUDY

## 3.1 Study Area

The target area is a residential district in Tokyo Metropolis. It covers an area of 0.1 $km^2$ and includes 350 buildings. The building types in this area are house, apartment, multi-storied buildings, and factory. The area consists of 27 blocks, which has about 15 to 20 buildings in each. The topography is flat and there is no slope in the area.

## 3.2 Aerial Photographs

In this study, a pair of the color aerial photographs with an approximate scale of 1 to 5,000 is used. These analog photographs are converted into digital images. One of the stereo pair photographs is shown in Figure 5.

Table 1 Features of GIS database provided by Tokyo Metropolitan Government

| DATA |
|---|
| Open Road |
| Express Way |
| Pave |
| River |
| Railway |
| Subway |
| Center Line of Open Road |
| Center Line of Express Way |
| Center Line of River |
| Center Line of Subway |
| Datum point |
| Elevation |
| Administrative Border |
| Use of Land and Building |
| Property of Building(Fire resistant, with fire protection system,wodden etc.) |

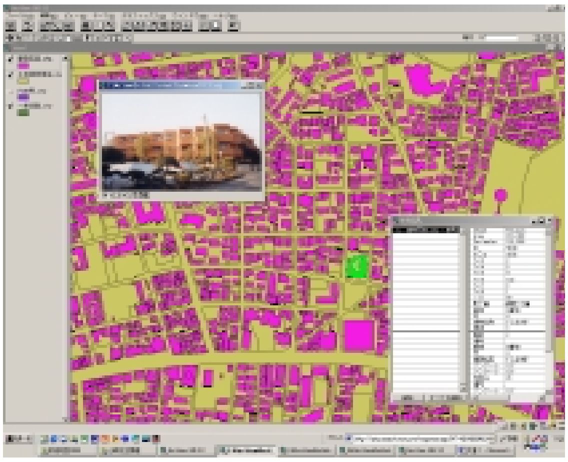

Figure 6 GIS database for validation

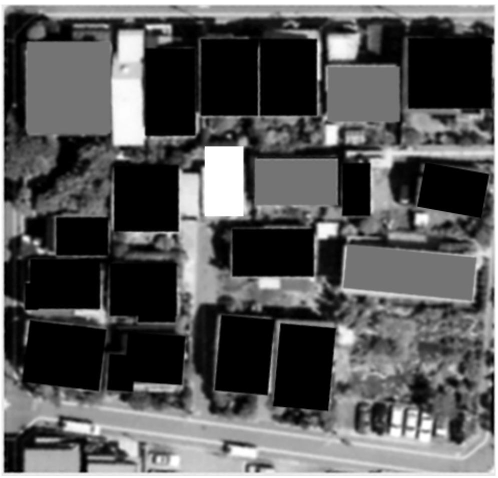


Figure 8 Evaluated heights

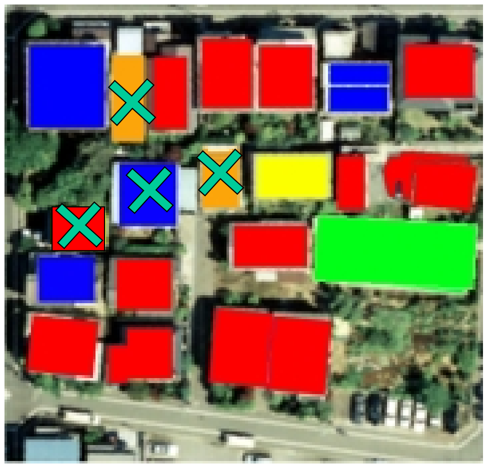


Figure 9 Classification result

### 3.3 GIS Database for Validation

The GIS database that was originally created by Tokyo Metropolitan Government is used for the validation data. The database was revised based on the result of the questionnaire to residents and the ground truth data surveyed by the authors. The features of the GIS database are detailed and range widely from road to building property data, such as number of stories and the age of the building (Table 1). This GIS database can give detailed data and the photographs taken by the authors only by point-and-click of an object (Figure 6).

### 3.4 Experiment Results

The result of texture analysis and the stereo matching is shown in Figures 7 and 8, respectively. The result of classification is shown in Figure 9. The classification result is compared with the validation GIS data. Almost all the classifications are succeeded except several buildings.

Figure 10 Photographs of classification-failed buildings

The non-wooden commercial building was mistaken as a wooden house. Referring to the GIS database in regard to the picture and properties, the building has similarity to wooden house with respect to the building scale and the roofing materials as seen in the left picture in Figure 10. The picture in the right side of Figure 10 shows that the building is a wooden house and this corresponds to the classification result. But the validation database says it is a non-wooden factory. The reason of this discrepancy may be caused either by mistaken data or un-updated data due to the renewal of the building after the database construction.

## 4. CONCLUSIONS

The automatic detection method of building properties using aerial photographs is proposed based on color and texture analysis, and 3D configuration using stereo matching. The method is applied for aerial photographs of a target area in Tokyo and the result is evaluated by the GIS database of ground truth data.

As a result of the study it is found that low-storied apartment buildings and multi-storied buildings are correctly identified and they can be classified into proper structural types. Although detached houses are identified correctly, some of them cannot be classified into appropriate structure groups. Therefore a further study is necessary considering the shape and materials of roofing to improve the accuracy of the proposed method.

In this study, because the judge of wooden or non-wooden building depends only on the texture analysis of the roof, the poor training data of roofing texture tend to lead to a detection error of building properties. Therefore typical texture patterns of roofing materials and the roof shapes should be summarized in the future study. In addition, it is needed to devise a method to recognize an enlarged building, a reconstructed building, and a special-shaped building.

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