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7—1 A Map-Based Approach for Extracting Object Information from Aerial Images

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Abstract

We have developed a map-based approach which enables us to efficiently extract object features from aerial images. We match an image with its corresponding map in order to estimate the object states in the image. This approach is characterized by its active use of a figure contained in the map as the object model for comparison. We determine the principal steps for the map-based approach for recognizing objects, and the steps are applied for obtaining the locations of missing buildings and the heights of existing buildings. The results of experiments using aerial images of Kobe City show that the approach is effective for automatically extracting urban-object information from aerial images.

1 Introduction

In the information-oriented society, one important part of the infrastructure is the Geographic Information System (GIS). For its effective use, the maintenance of map data is indispensable. Moreover, to further develop GIS, object information, such as heights and previous locations, is also necessary. Because a field survey is time consuming and requires a lot of manpower, aerial images are used for obtaining regional information. To update existing map data, aerial images provide newer information, but they are complex and involve irregular features. Therefore, to help solve this problem, the existing map can be used as guiding information for analyzing the aerial images. By fusing an aerial image and its corresponding map, newer information for updating the map is obtained. To date, several methods have been suggested for analyzing urban scenes from aerial images with map information [1]-[3]. For extracting urban objects like roads or buildings, in most cases, the figures contained in a map were used for estimating the area including an object and connecting the image segments to form the object. These methods, however, could not use entire map properties. We therefore propose an essential map-based approach to extracting object features from aerial images. This approach is characterized by using figures in a map as object models for comparison. The figures contained in the existing map provide us much useful information such as presence, location, shape, size, and kind of objects. When an image is matched with its corresponding map, the information provided by the map helps to improve the recognition of the objects.

In this paper, a map-based approach for analyzing aerial images is developed. First, we determine the principal steps of an map-based approach in urban object analysis. Then, we applied the steps to obtain locations of missing buildings and heights of existing buildings. Finally, we carried out experiments using aerial images of Kobe City, and the results show that the approach is effective for automatically extracting object information from aerial images and updating the map.

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2 Map-Based Approach to Aerial Image Analysis

2.1 Concept of Map-Based Approach

Figure 1 illustrates the concept of the map-based approach for analyzing an aerial image. The geographic database in the GIS supplies expert knowledge [4]-[6]. Moreover, the shape and attributes of map figures stored in the database directly become object models. To use the figures as the object models, we match the map to the image in advance. The map we use is a digital map in vector format in which the figures are represented by the polygon (x,y,z) with attributes and time stamps. The figures can be easily picked out, moved and transformed. In this way, an aerial image and its corresponding map are fused. To recognize an object, the corresponding figure becomes the object's model, and newer information extracted from the image is returned to the database for updating the map.

2.2 Principal Steps of Map-Based Approach

In the map-based approach, we classify the approach into four principal steps: *clipping*, *sieving*, *probing*,

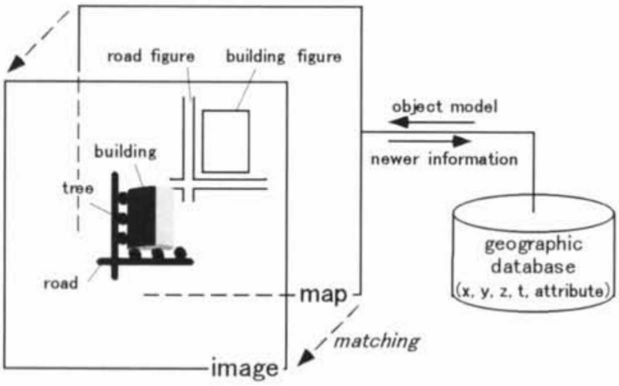


Fig. 1 Concept of a map-based approach to aerial image analysis

and *reserving* (Fig. 2). *Clipping* is a traditional step but we have developed the others.

Clipping. The object area is estimated by using the matched map figure. This step is especially useful when we restrict the area including the object. This step is also used for

- estimating object shape and connecting image segments to form the object,
- estimating object edge location and direction,
- estimating the shadow area around the object,
- estimating the location of near objects.

Sieving. The object location and shape are defined by the matched map figure. Ambiguous pixels around the object are sieved out by matching the figure shape and the object[7].

This step is used for

- extracting the pixels of an object that is difficult to separate from the surroundings because of the poor contrast between the object and the surroundings,
- dividing the continuous area of two objects touching each other, like two houses, into separate areas,
- specifying the area in which objects used to exist.

This step may be a special case of *clipping*.

Probing. The object position is searched for by using the object's corresponding figure as the structural template of the object. The figure projected onto the image becomes a template reflecting the object property. By applying the template-matching technique, the location and the structure of the object is designated.

Reserving. The past information of an object is reserved in the corresponding map figure. The present object structure is compared with the past structure which is reserved in the corresponding figure. When new information about the object is obtained, the difference between the past and the present state is added to the existing information about the object. Thus we can obtain the object information from past to

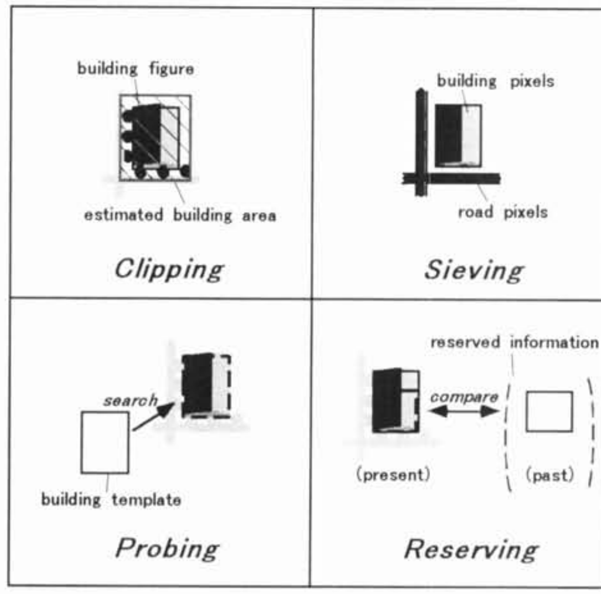


Fig. 2 Principal steps using a map figure in object analysis

present.

3 Extracting Building Information

We focus on buildings since they are the most significant urban objects among man-made structures. We apply steps in Sec.2.2 in order to obtain location of missing buildings and the heights of existing buildings in an obliquely viewed (i.e., non-nadir) image (Fig. 3). The missing buildings are extracted by the feature analysis (using the *sieving* step), and the building heights are obtained by the structure analysis (using the *probing* step). For analyzing the buildings by using map information, we calculate, in advance, the relationships between the map coordinates and the image coordinates, and we match the image with the map transformed perspectively.

Extraction of missing buildings. To extract a missing building, we define its past location and shape by matching the corresponding figure, and we extract the pixels included in the figure (*sieving*). Because of existence of the surroundings around the object, because of matching error between the figure and the object, and because of data error of the figure, the extracted pixels may contain the pixels of the next object such as an adjacent building or a tree. We therefore investigate the building feature by statistically analyzing the texture of the extracted pixels; for example, the brightness, hue, and saturation distribution of the pixels. When the feature of the building is defined, the features of pixels included in the figure indicate whether the building

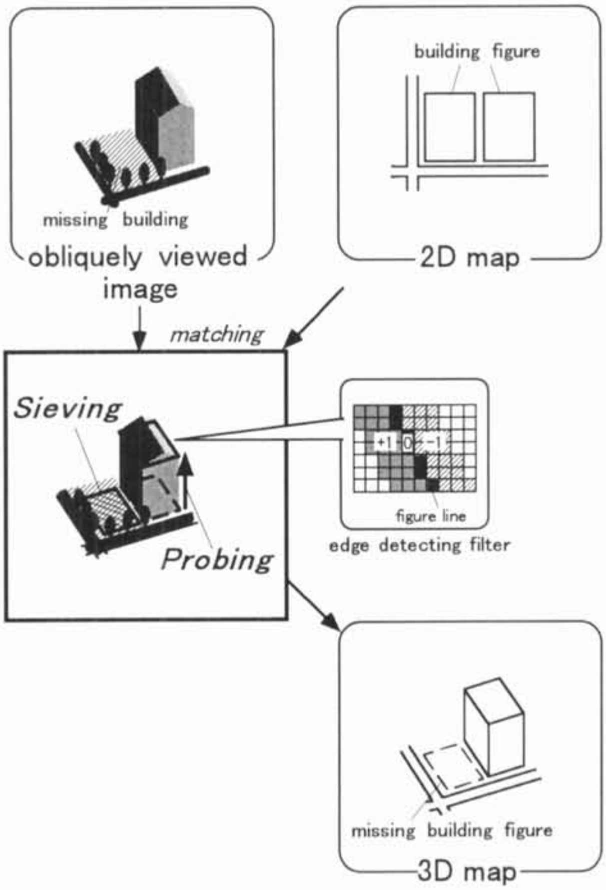


Fig. 3 Application to extracting building information

exists or not in comparison with the building feature.

Extraction of building heights. To obtain the heights of buildings, we assume the 3-dimensional shapes of building structures as a rectangular parallelepiped. Thus we can use the building figure also as the template for the building roof (*probing*). The figure is first matched to the base of the building and then moved upward to the building's roof. When the figure shape matches the image of the roof , the position of the figure indicates the height of the building. To confirm whether the figure matches the roof, an edge detecting filter is activated along the figure lines when the figure is moved upward. The filter measures the brightness difference between the inside and outside of the figure; that is, the edge magnitude along the figure lines. In the aerial images, the pixel brightness changes greatly between that of the building's wall and that of the roof. When the edge magnitude along the figure lines indicates the maximum, the figure matches the roof. The size of the filter depends on the building size and the pixel resolution. The accuracy of the measured building height depends on the accuracy of the figure shape, the pixel resolution, and the accuracy of matching between the roof and the figure.

4 Experiments

We summarized the efficiency and the accuracy of the proposed method by applying the map-based approach to aerial images of Kobe City taken after the earthquake in 1995. The pixel resolution of the image is about 0.5 m, and the scale of the corresponding map is 1:2500. We extracted the missing buildings and the building heights by the method discussed above. We used the obliquely viewed aerial image in which 3-dimensional shapes of buildings are expressed.

First, we determined the relationships between the map coordinates (x,y,z) and the image coordinates (u,v), and they are defined by,

$$u = \frac{C_{11}X + C_{12}Y + C_{13}Z + C_{14}}{C_{31}X + C_{32}Y + C_{33}Z + 1} \tag{1}$$

$$v = \frac{C_{21}X + C_{22}Y + C_{23}Z + C_{24}}{C_{31}X + C_{32}Y + C_{33}Z + 1}, \tag{2}$$

where C_{11} to C_{33} are the map projective coefficients that describe the projection from map point (x,y,z) to image pixel (u,v). We chose some buildings whose current heights are known and selected more than six pairs of image pixels and corresponding map points. We calculated the map projective coefficients from these pairs by the least-mean-squared error method, and we matched the image with the map transformed perspectively according to Eqs. (1) and (2).

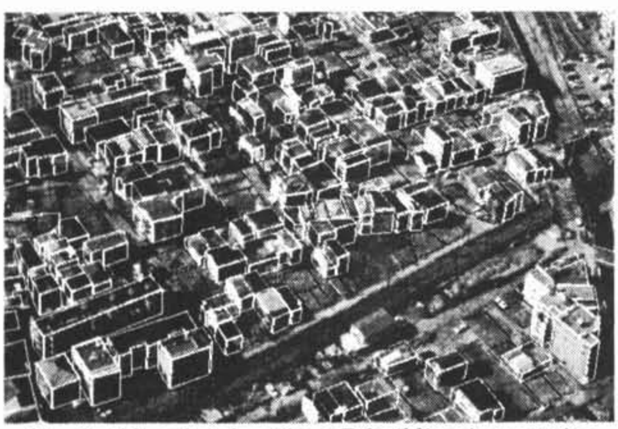
After matching the map to the image, we extracted the missing buildings (Fig. 4(a)) using the *sieving* step and then the heights of the remaining buildings (Fig.4 (b)) using the *probing* step. Table 1 lists their extraction rates.

Missing building extraction. The main cause of extraction failure is that another object hides most of the missing building area. Over extraction occurs because some existing building areas show the same feature as the missing building area.

Building height extraction. The main cause of the extraction failure is that the roof shape is more complicated than the figure shape. And the figure position where the edge magnitude along the figure lines indicates its maximum does not correspond to the roof. This failure may be improved by more precisely modeling the complicated roof shape.

As mentioned above, there are still some points that must be improved in our future approach. However, we extracted 90% of the missing buildings and we obtained 80% of the heights of the remaining buildings. The results show that the developed approach is effective for obtaining object features from aerial images. This approach also helps rapid updating of maps in a GIS database.

(a) Missing buildings extraction



(b) Building heights (*i.e.*, 3D buildings) extraction

Fig. 4 Experimental results of building information extraction applied to an image of Kobe City (taken after the 1995 earthquake).

5 Summary

To obtain object features over a wide area automatically, we have developed a map-based approach for extracting object information from aerial images. This approach is characterized by its active use of a figure contained in a map as the object model for comparison. By fusing an aerial image and the corresponding existing map, the map provides a model for analyzing objects, and the analyzed results update the map. The approach enables the efficient extraction of object features from the images and contributes to updating maps in a GIS database.

In this paper, we classify the steps of the map-based approach into four types: *clipping*—estimating object area; *sieving*—sieving ambiguous pixels; *probing*—searching for a object structure; *reserving*—reserving the object information. Furthermore, we apply the *sieving* step for extracting the location of missing buildings and the *probing* step for obtaining building heights. The experimental results from aerial images of Kobe City show that the approach is effective for extracting object information.

Table 1 Extraction rates of building information

	correct extraction (%)	extraction failure (%)	over extraction (%)
missing buildings	81	19	10
building heights	93	7	—

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