

BUILDING RECONSTRUCTION BY COMBINING 2-D TOPOGRAPHIC MAPS AND HIGHLY OVERLAPPED AERIAL IMAGES

Tee-Ann Teo¹, Liang-Chien Chen², Hong-Kuei Cheng³, Hsin-Ta Liu⁴

¹Postdoct., Center for Space and Remote Sensing Research, National Central University, Taiwan.

²Professor, Center for Space and Remote Sensing Research, National Central University, Taiwan.

³Technical Manager, CECI Engineering Consultants, Inc., Taiwan.

⁴Senior Engineer, CECI Engineering Consultants, Inc., Taiwan.

E-mail: {ann, lcchen }@csrsr.ncu.edu.tw; {tc561, sdliou}@ceci.com.tw

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ABSTRACT: The objective of this investigation is to reconstruct building models by the integration of high overlapping aerial images and building boundaries. The proposed method includes four major parts: (1) polygon tracing, (2) 3-D building polygon generation, (3) 3-D structural lines extraction, and (4) Split-Merge-Shape building modeling. First, the operator locates the initial lines by a graphical user interface. The initial lines are refined by image matching of high overlapping images. Finally, the precise 3-D lines and 3-D polygons are processed into a 3-D modeling by an inference engine. The experimental results indicate that the proposed method may reconstruct the 3-D building model effectively.

1. INTRODUCTION

The importance of cyber city modeling is increasing due to the needs for accurate 3-D spatial information for urban planning, construction, and management. A cyber city is simply a replica of a real city reconstructed in cyber space that can be stored in an information system. Such models are an essential part of urban and environmental planning, hazard mitigation, telecommunications, flight simulation, transportation planning, map revision and many other aspects. In addition, the timely information they help to provide is valuable to decision makers for city management. The aim of this investigation is to establish building models from high overlapped aerial images.

Building model is one of the most prominent and attractive elements in a cyber city. These 3-D building models are mainly reconstructed from aerial images, laser scanning point clouds and vector maps. The first step of building reconstruction from aerial images is to extract the image features. One may then use the extracted features to model the buildings through a hypothesis process. This means that the crucial issue for building reconstruction from image data is to extract the building features. Reconstruction strategies based on laser scanning are mainly concerned with the detection of roof planes. The planar features are extracted first, then they are used to derive the line features. The building model is obtained by integrating the planar and linear features (Teo, 2008).

The development of digital aerial camera provides the possibility of acquiring high overlapping aerial images with high spatial resolution. In addition to its high spatial resolution that improves the capability of image interpretation, the high overlapping images provide favorable geometrical configuration with high redundancy. The high similarity of stereo images is, thus, beneficial to the reliable image matching. Hence, the 3-D point clouds from the image matching have the great

potential in 3-D modeling. The topographic maps provide the distinct boundaries for building modeling. The strategies of building reconstruction with existing topographic maps may improve the quality, cost, and efficiency of building modeling (Zhang and Walker, 2007).

The image matching is an important process to generate the conjugate points as well as object coordinate. There are two kinds of image matching approaches, i.e., image-based matching (Habib *et al.*, 2003) and object-based matching (Zhang and Gruen, 2006). The image-based matching starts from an image point of the master image. Then, the corresponding conjugate points are obtained from the slave images. The image point of the master image is fixed in the image-based matching. On the contrary, the object-based matching starts from an object point in the object space. Then, the object point is back-projected to the image space and the similarity of images in a specific window will be calculated. The image point for image matching is not fixed in the object-based matching.

The objective of this investigation is to establish building models for cyber city. The topographic maps and the high overlapped aerial images are integrated to produce the accurate building models. The 2-D building boundaries are extracted from topographic maps while the 3-D line features such as building structure lines are extracted from stereo images. These lines are then structuralized to form a model. The proposed method includes four major parts: (1) polygon tracing, (2) 3-D building polygon generation, (3) 3-D structural lines extraction, and (4) Split-Merge-Shape building modeling (Rau and Chen, 2002). First, the operator locates the initial lines by a graphical user interface. The initial lines are refined by image matching of high overlapping images. Finally, the precise 3-D lines and 3-D polygons are processed into a 3-D modeling by an inference engine.

2. METHODOLOGY

The proposed methods include four major parts: (1) polygon tracing, (2) 3-D building polygon generation, (3) 3-D structural lines extraction, and (4) Split-Merge-Shape building modeling. The workflow of the proposed methods is shown in Figure 1

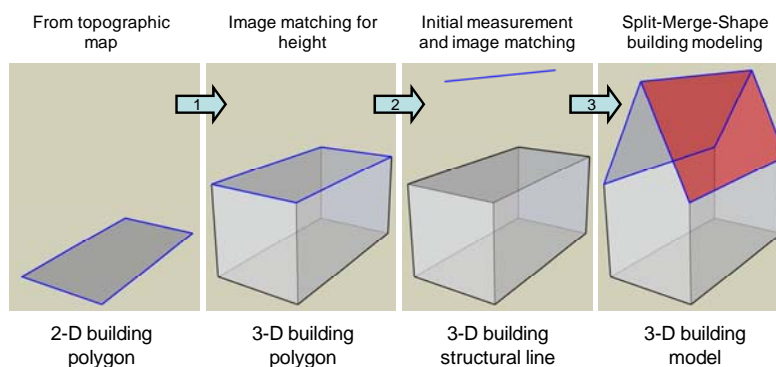


Figure 1 The scheme of the proposed analyses

2.1 Polygon tracing

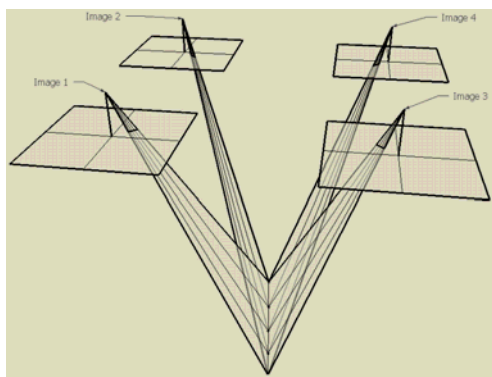
The procedure starts by tracing the building polygons. The building boundaries are delineated by polylines from which the topology can be reconstructed. The building polygons have to be enclosed for further processing. The topographic maps provide distinct building boundaries because the boundaries are derived by human interpretation. In general, these building ground plans are two-dimensional. The building boundaries in CAD system are stories as lines. Each building is the

combination of line segments. In order to recover the topology of building line segments, we use commercial software ArcInfo[®] to generate the closed 2-D building polygons.

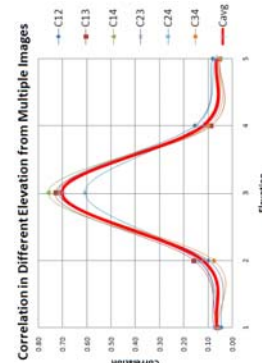
2.2 3-D building polygon generation

After the polygon tracing, we have to assign the building height of the 2-D building polygons. In general, the building's height is simplified as the number of floors due to the traditional mapping convention. The stories number is given as an integer from topographic map. From this, we can generate the initial height by estimating the height of each story. However, the initial height is not accurate due to the simplification. A multiple image matching process is needed to obtain the accurate height.

The planimetric coordinate of building, i.e., (E, N), is from the topographic map. The unknown parameter is merely the height of a building. Since the E and N coordinate are fixed, we select the object-based matching method in this stage. The multiple image matching constraint include geometrical and similarity constraints. The epipolar geometric constraint is applied in the image matching (Schenk, 1999). The advantage of using the epipolar images is to reduce the pull-in-range of image matching. The similarity index is the normalized correlation coefficient (NCC) (Schenk, 1999). In order to consider the similarity of multiple images simultaneously, a summation of NCC from each pairs is calculated (Zhang and Gruen, 2006). First, an object point is back-projected to each stereo pairs and the NCCs in a specific height are calculated. Then, to modify the height of object point and obtains the NCCs in different heights, the average of NCCs is calculated. The elevation of the highest average NCC is selected as the elevation of an object point. Figure 2 illustrates the matching process. Figure 2a illustrates the back-projection of object points while Figure 2b shows the NCC for each stereo pairs and average of NCCs.



a. Object-based multiple images matching



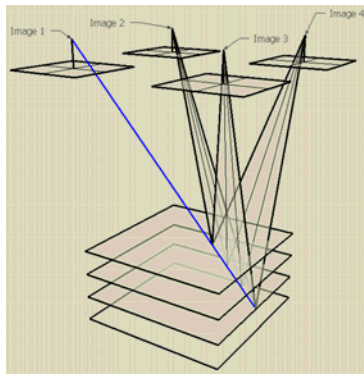
b. NCCs and SNCC

Figure 2 Illustration of 3-D building polygon generation

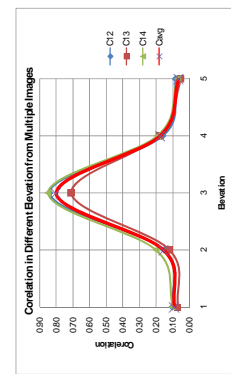
2.3 3-D structural lines extraction

In some cases, an image feature from automatic feature extraction does not correspond to an object feature, which could cause ambiguity in the reconstruction procedure. Hence, the semi-automatic process is selected in this investigation to provide the promising location of the structural lines. The first step of structural lines extraction is to digitize the initial location of structural lines in a single image. Then, an image feature extraction method is applied to refine the location of structural lines. Finally, the multiple images matching obtain 3-D structural lines.

In the manual digitization, an operator is needed to digitize the coarse building corners to get the initial location of structural line in a single image. Then, a buffer zone is created around the initial location. The Harris corner extraction is applied to refine the corners location. The image-based matching is selected in the structural line matching. First, the ray-tracing method is used to determine the initial object coordinates. Then, the back-projection method is used to predict the matching area. This multiple image also utilizes the summation NCCs to get the object coordinates of structural lines. Figure 3 illustrates the matching process. Figure 3a illustrates the ray-tracing and back-projection of an image point while Figure 3b shows the NCC for each stereo pairs and average of NCCs.



a. Image-based multiple images matching



b. NCCs and SNCC

Figure 3. Illustration of 3-D structural lines extraction

2.4 Split-Merge-Shape building modeling

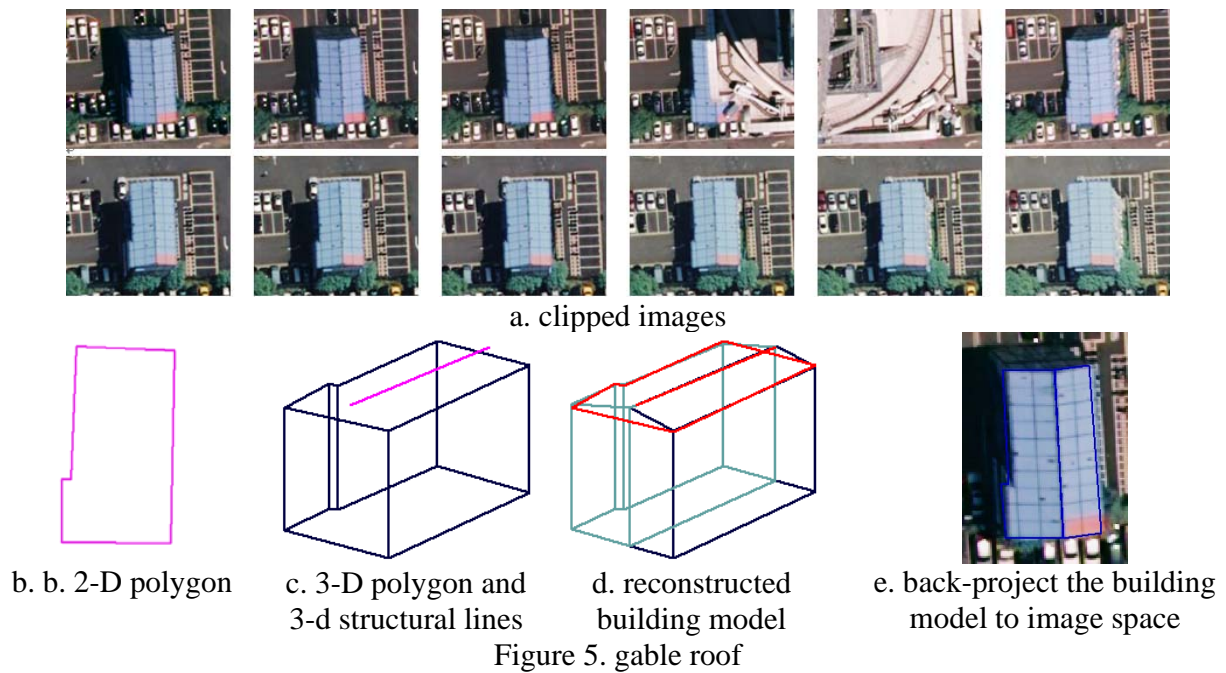
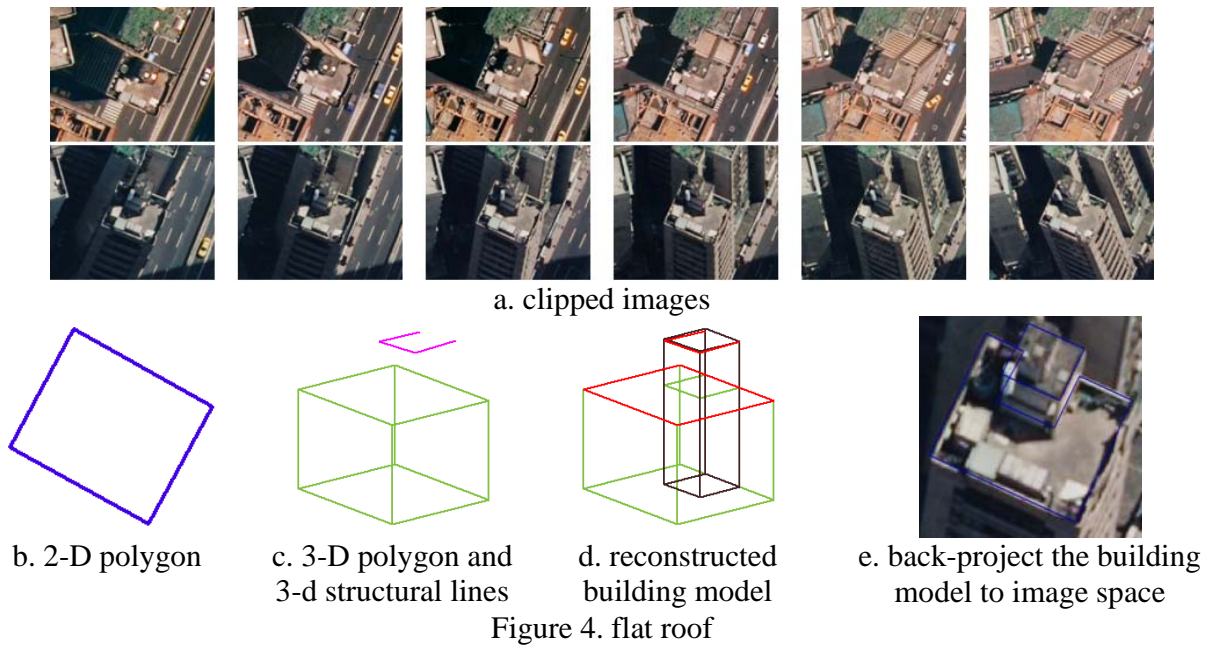
In this stage, the 3-D building polygon and 3-D structural lines are combined in precise building modeling. A Split-Merge-Shape method (Rau and Chen, 2003) is selected in building modeling. The Split and Merge steps are the two procedures for topology reconstruction. The Shape step uses the available roof-edge height information to determine an appropriate rooftop. The splitting and merging procedure is worked in the 2-D space. In the Splitting step, a line-segment is chosen as a reference. If any roof-primitives contain this roof-edge, we split the roof primitive into two. For successful roof-edges, a combination of the possible roof-primitives is constructed. Every two connected roof-primitives are analyzed successfully. If the boundary shared between them does not correspond to any 3-D roof-edges, the two roof-primitives will be merged into one. The Shape process is worked in 3-D space. The first step of shaping is to assign a possible height for each roof-edge from its corresponding 3-D roof-edge. The second step is to define the shape of a rooftop according to the height of the independent edges. If more than two independent edges exist and are sufficient to fit into a planar face, then least-squares coplanar fitting can be applied.

3. EXPERIMENTAL RESULTS

The test area is located in Taipei, a metropolis in northern Taiwan. The topographic maps are with a scale of 1:1,000. The spatial resolution of DMC digital aerial images is 20 cm. Twelve images from 2 strips are included in the experiment. There are 75% and 40% overlap in the in-flight and cross-flight direction respectively.

Case I is a multiple flat roof. The respective images are shown as Figure 4a. The original 2-D boundaries are a rectangle shown as Figure 4b. We use the multiple images matching to obtain the

building height. Then, the 3-D structural lines are also determinate by image matching. The 3-D building polygon and 3-D structural lines are shown as Figure 4c. Figure 4d is the reconstructed building models. We back-project the generated building model to the original image. Figure 4e shows the consistence of the model and image feature. Case II is a gable roof. The reconstructed building model is shown as Figure 5. The result also showed the high consistence between the models and the original images.



In the accuracy analysis, we select the building corner of gable roof for evaluation. The reference data is the manual measurements from stereo graphic. We use different number of images to perform the image matching. Table 1 shows the height of building corners. Compare the matching result and reference data, most of the corners show the accuracy less than 30 cm except the corner 2 & 3 of Case C as it contains 2 occlusion images among the 6 images.

Table 1. Comparison of building corners

Case	# Images	Strip ID	# Pairs	Corner 1	Corner 2	Corner 3	Corner 4	Corner 5	Corner 6
A	12	1,2	66	19.80	20.00	19.80	19.60	19.60	19.80
B	10	1,2	45	19.80	20.10	19.90	19.60	19.60	19.80
C	6	1	15	20.10	20.60	18.50	19.30	19.50	19.50
D	6	2	15	19.70	20.00	19.80	19.80	19.50	19.50
E	4	1,2	6	19.70	20.10	19.90	19.70	19.90	19.90
Reference data				19.80	20.00	19.90	19.60	19.60	19.80

4. CONCLUSIONS

In this investigation, we have presented a semi-automatic scheme to integrate the topographic maps and highly overlapped aerial images in building reconstruction. The results show the potential of 3-D building model generation by the fusion of various data. The experimental results are summarized as follows: (1) The initial building modeling provided by topographic maps is an effective process, but the height of the preliminary model is not accurate to meet some application. (2) The initial digitize in single image may reduce the ambiguity of image feature extraction. (3) The highly overlapped image provides redundancy measurement in image matching. The summation of correlation from each pairs may consider all images simultaneously.

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