

AN INTERACTIVE SCHEME FOR BUILDING MODELING USING THE SPLIT-MERGE-SHAPE ALGORITHM

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ABSTRACT:

The most important feature in urban modeling is the 3D building model. It is essential in many applications, such as 3D GIS, cyber city, true-orthophoto generation, etc. Due to the huge demand of 3D building model, an effective solution for geometrical building modeling is required. In this paper, a 3D building modeling based on the Split-Merge-Shape (SMS) algorithm is presented. Since the SMS algorithm adapts 3D visible roof-edges for building modeling, a semi-automatic scheme for measuring 3D visible roof-edges from multi-view aerial images is proposed. In the SMS algorithm, the SPLIT and MERGE steps are the procedures for topology reconstruction from isolated roof-edges. The SHAPE step uses the available roof-edge height information to define an appropriate rooftop. With the SMS method, the topographic mapping of buildings, and geometric building modeling, can be seamlessly integrated into a unified procedure. In the paper, we will start with an overview of state-of-the-art technologies on the subject of building modeling. The SMS algorithm is then presented and integrated with the proposed semi-automatic scheme for 3D roof-edges measurement. A preliminary test utilizing a set of four 1:5,000 aerial images is demonstrated. Experimental results indicate that high reliability and accuracy may be reached with limited manual efforts.

1. INTRODUCTION

Since the 3D building model is the most important feature in urban area, the creation of 3D virtual world from remote sensed data is getting more attention during the last decade. Many kinds of remote sensing data, such as 2D stereo images and LIDAR, were adapted as data source by most of the researchers. The generated 3D building model is essential in many applications, such as true-orthophoto generation (Rau & Chen, 2002), map revision, cartographic database compilation, change detection, transportation, urban planning, environmental planning (Lange, 1999), geo-visualization (Keim *et al.*, 2004), flight simulations, noise and air pollution simulations, microclimate studies, wireless networks telecommunication planning (Siebe & Buning, 1997; Leberl, *et al.*, 1999), virtual tourism information querying (Volz & Klinec, 1999), etc. An effective solution for the generation of reliable and accurate building models is thus more urgent than ever. The related techniques can be generalized as 3-D mapping.

Since 3-D mapping technology is getting important, some Digital Photogrammetric Workstations (DPWs) have developed new functions that will create DBMs directly, and integrate them into topographic mapping. However, image occlusion is still the biggest problem in the manual delineation process. The operator is responsible for the measurement of roof corners and the structuring of building models. Whenever image occlusions occur, the operator has to estimate the hidden corners from conjugate images. The whole process is time-consuming and labor intensive, as well as tedious, inefficient and produces with a limited accuracy, especially for connected buildings in densely built-up areas. Additionally, the designed DPWs need special hardware and software for stereo viewing and measurement. For example, they need a stereo-monitor, a high-end stereographic display card, a set of hand wheel and foot plate for measurement, etc. The cost will increase the budget of a company and withdraw their competition advantageous.

Except for the above *manual operations* necessary for building modelling in some DPWs, most of the related work can be categorized into two approaches, according to the degree of human intervention required for topological reconstruction. The two approaches are the *automatic approach* (Baillard. and Zisserman, 2000; Fischer, *et al.*, 1998; Henricsson, 1998) and the *semi-automatic approach* (Gülch, *et al.*, 1999; Grün & Wang, 1998).

Gülch, *et al.* (1999) proposed the use of monocular images and building-based measurements for 3-D city model creation. Their approach is based on a *semi-automatic* scheme. In manual modelling, the operator's task is to fit a wire-frame building model, which is selected from a predefined model database, to the images, via monoscopic viewing. The operator has to adjust the wire-frame model to fit the corresponding image features. A complex building is decomposed into some basic building types and constructed using a Constructive Solid Geometry (CSG) tree. The operator is also responsible for handling the CSG tree structures. Although the approach is innovative, the operator takes too heavy a responsibility, necessitating a qualified operator. The approach may be efficient for simple structure and specific type of building, but not for groups of connected buildings in densely built-up areas where occlusions and shadows frequently occur.

Grün & Wang (1998) proposed a topology builder, i.e. the CC-Modeler system, for the generation of building models. The system is based on a *semi-automatic* approach, utilizing manually measured 3-D point clouds. The measurement of 3-D point clouds, denoting all roof corners must be complete, including any hidden ones. The system is a model-based approach, but it can be applied to general objects, such as roads, rivers, parking lots, ships, etc. During data acquisition, 3-D point clouds are manually coded as boundary points and interior points, according to their functionality and structure. Although the system is operational, some of their limitations cannot be ignored. Those limitations are stated as follows. (1) The measurement of hidden corners caused by building occlusions is

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necessary to assure the completeness of a roof unit. (2) The structuring may fail if the processed roof unit or object is not in the pre-defined model database. (3) The boundary point digitizing sequence must be restricted to being point-wise. (4) Each roof unit or object needs to be processed independently, which leaves connection problems between two buildings to the operator.

2. METHODOLOGY

In this paper, we proposed an interactive scheme for 3-D building modeling using multi-view aerial photos with known absolute orientation parameters. In order to solve the precise stereo correspondence problem, we combine the manual rough measurement via monoscopic viewing, followed by an automatic feature line extraction and image matching technique to extract the roof-edge's 3-D line-segments. Finally, in 3D topology and geometry reconstruction, the SPLIT-MERGE-SHAPE (SMS) algorithm (Rau & Chen, 2003b) is adopted to generate the 3-D building model from those 3-D line-segments. The flowchart of the proposed scheme is depicted in Fig.1.

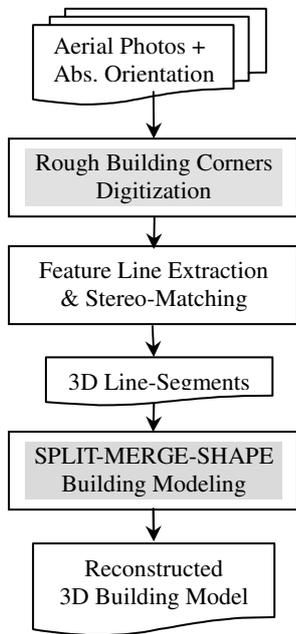


Figure 1. Flowchart of the proposed scheme.

The major work of this paper is mostly on the interactive scheme. The idea is to adopt the reliability of human eye and the calculating power of a personal computer. Additionally, the whole scheme can also reduce the hardware requirement that any graphical card is enough with no necessary of expensive stereographic card, monitor, etc. For human eye, it can effectively distinguish the target from massive information of aerial photos. The computer provides precise estimation from huge calculation. In figure 1, two shaded-boxes denote the human-machine interactive part of this research. One for initial guess of stereo measurement while the other is for geometrical building modelling.

2.1 Rough Building Corners Digitization

In addition to the original multi-view aerial photos, the absolute orientation parameters are necessary in this stage. In the digitisation of building corners, we utilized the top-down

ray-tracing method and bottom-up back-projection technique for manual stereo measurement via monoscopic viewing, as shown on figure 2. At beginning, the operator can choose one building corner on the master photo and digitise it roughly. Combining absolute orientation parameters (X_1^c, Y_1^c, Z_1^c) with the digitised image coordinates (x_1, y_1) in the master photo we can determine the ray direction. The operator can thus adjust or provide a ground height (Z_1) to get a ground coordinates (X_1, Y_1) . By applying the bottom-up technique, the projected photo coordinates (x_2, y_2) on the other aerial photos can thus be calculated and projected on the search photo. So, the operator's workload is simplified to adjust a target's ground height and match its corresponding point.

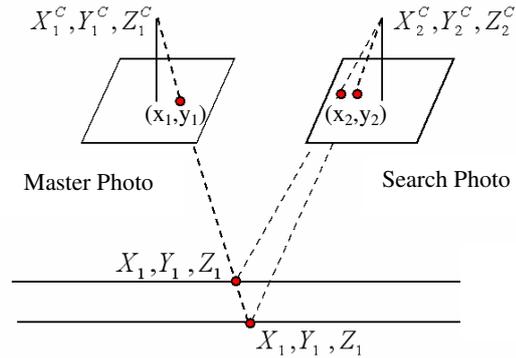


Figure 2. Stereo measurement via monoscopic viewing.

2.2 Feature Line Extraction & Stereo Matching

In 3D building modelling, the SMS algorithm (Rau, 2002; Rau & Chen, 2003b) was adopted. In which, the primary ground object is the 3D roof-edges, which can be extracted from 2D image feature line and stereo matching. A brief description of every step is discussed in the following.

At first, an operator may manually digitise a sequence of coarse building corners to get the initial location of building boundary. Two consecutive building corners will construct an image feature line. A buffer zone is created around the feature line and the following image processing technique is applied within the buffer zone only. A fast straight-line extraction technique proposed by Rau and Chen (2003a) is adopted in this study. In which, an SNN filter is utilized for noise reduction and a multi-resolution edge detection technique is used to get edge magnitude. A local maximum tracing method will thin the edge as single pixel width. A modified Hough transform with principal axis analysis can accelerate the extraction of straight-line.

There are numbers of feature line stereo-matching algorithms that have been published in the field of photogrammetry and computer vision. However, in this paper we adopt the epipolar geometry constrain and grey value consistence for stereo matching. Once a feature line has been extracted on the master photo, the other feature lines on the search photos is also considered for automatic detection. There may exist no one or more than one feature lines in the buffer zone. For a set of four-views stereo photos, the maximum number of stereo-pairs combination is six. It increases the possibility and redundancy of stereo matching in a dense and complex environment that hidden effect may happen. The normalized cross correlation (NCC) method is utilized for calculating the similarity index. It is calculated on both side of a feature line and compared

separately. In case one of them exceed the similarity threshold, they are considered as a conjugate line and a further space intersection is applied to get a 3D roof-edge.

2.3 3D Building Modelling

In this section, the SMS algorithm (Rau & Chen, 2003b) for 3D building modelling is illustrated. In the real world, it is difficult to describe all types of buildings using a single comprehensive building model database. In our approach, a building model may be decomposed into several planar roof-primitives. A roof-primitive may be a part or a complete building. Each roof-primitive is a planar rooftop, (e.g. a horizontal or oblique plane), with its boundary projected onto the ground as a polygon. One roof-primitive, or a combination of roof-primitives, can be reformed as a *polyhedral building model*.

The primary data source for 3D building modelling using the SMS algorithm is the 3D roof-edges. The 3D roof-edges may come from totally manual stereo measurement using expensive stereographic equipment or comes from a semi-automatic way as described in the previous section that adopts the popular graphic card only.

The key for the realization of 3D building modelling using the SMS algorithm is to create an initial building model, which is the first roof-primitive with a known topology. The initial building model is simply built in such a way that an operator needs only to specify the Area Of Interest (AOI) with a polygon. By the incorporation of a reasonable height, a volumetric representation of the initial building model, which covers all of the 3-D roof-edges in a process. Briefly speaking, the creation of initial building model has the following two important meanings: (1) the first building model with a known topology, and (2) the selection of working line-segments.

A pre-processing of the input 3D roof-edges is necessary before modelling. The reasons are one refers to the adjustment of geometric irregularities due to stereo measurement errors, the other to obtaining a topology error-free solution. Many geometric irregularities due to the errors of manual stereo measurement can happen, such as: (1) two collinear lines are misaligned, (2) rectangular buildings are skewed, (3) two consecutive line-segments intersect and cause overshooting, and (4) gaps due to image occlusions, especially in a densely built-up area, may cause incorrect modelling. These kinds of situations should be solved before building modelling. Since the roof-edges are defined in the 3-D object space, these pre-processing steps are also performed in the object space.

The SPLIT and MERGE processes can sequentially reconstruct the topology between two consecutive line-segments and then reform the areas as enclosed regions. In splitting, one line-segment is chosen as a reference. If any roof-primitives contain this roof-edge, we SPLIT them into two. For successive roof-edges, a combination of the possible roof-primitives is constructed. The splitting action is similar to the manual inference of hidden corners. The merging procedure is also worked on the 2-D horizontal plane. Every two connected roof-primitives are analyzed successively. 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 object space. The first step of shaping is to assign a possible height for each roof-edge from its corresponding 3-D roof-edge. Every roof-edge is automatically labeled as a *shared edge* or an *independent edge* at first. The height information for an *independent edge* can then be assigned

and fixed from its corresponding 3-D roof-edges. 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. Otherwise, the system will provide the most possible solution by *consecutive-coplanar analysis*, which is used to find a possible planar rooftop using consecutive line-segments or any two non-consecutive but coplanar ones.

The proposed SMS method is designed to have some *post-processing functions* for visual inspection and modification. In the visual inspection stage, each generated roof-primitive is examined both on the ground view and 3-D view. The user can *select* the roof-primitive of interest on the ground view. The selected roof-primitive together with the original 3-D roof-edges will be shown in the 3-D view. Whenever the selected roof-primitive does not fit the original roof-edges, *reshaping* is necessary. The system will provide all possible solutions by the consecutive-coplanar analysis and show them on the screen one by one. The operator can thus choose the correct one by comparing the original stereo-pair.

3. CASE STUDY

In this section, a set of manually measured visible roof-edges and three cases of semi-automatic measured roofs are evaluated. The first one is to demonstrate the feasibility and power of the proposed SMS method. The second one illustrates the potential of the proposed interactive scheme for 3D building modelling.

3.1 Manual Measurement of Visible Roof-Edges

The first test data set was measured manually using a DPW. The original data is a four-views aerial photo, which is located at the Fu-Zen University, TAIWAN, as shown in figure 3. The fly height is 1,700 meters with a scale of 1:5,000 and a ground sampling distance around 12.5 cm.

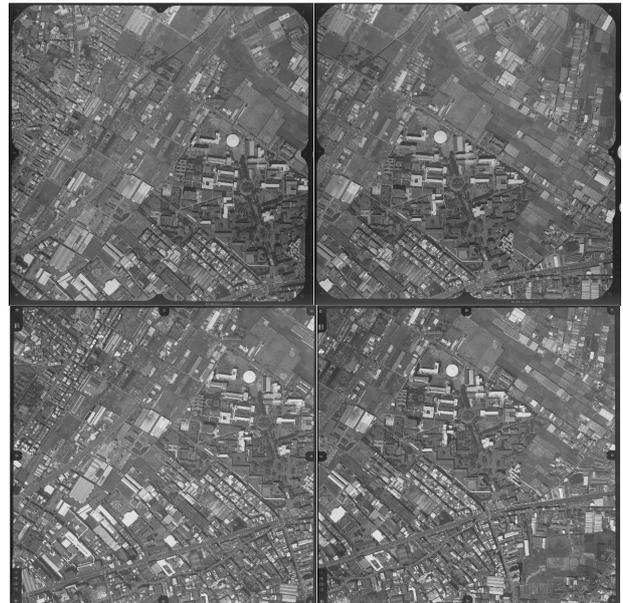


Figure 3. Multi-views aerial photos.

The content of this data set can be abstractly categorized into three parts. One is the university campus. In which the buildings are large with complex boundary, and are separated to each other with a distance. The second category is a high-density built-up area with groups of connected and rectangular

buildings. The third part is a high-density built-up area with groups of connected, complex rooftops, and less-orthogonal buildings. The number of measured roof-edges is 6,363. Figure 4 depicts the reconstructed polyhedral building models for this data set displayed using the 3-D visualization tool. The number of roof-primitives created using the SMS method was 1,809. The splitting and merging process was totally successful after the correction of blunder measurements. However, 38 roof-primitives failed at the shaping stage, giving a success rate of 98%. The 2% failure rate was totally recovered using the provided *post-processing functions*, without any manually editing of building models.

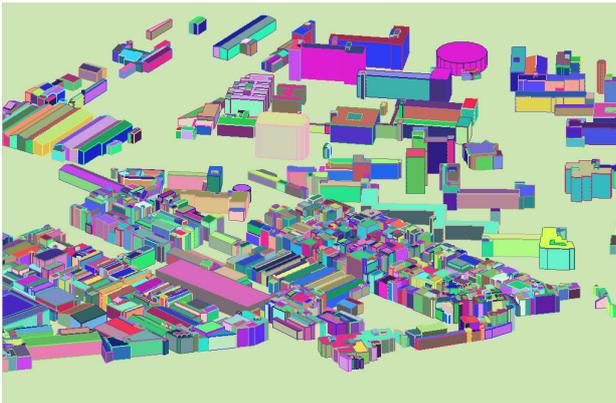


Figure 4. The generated 3D building model based on manual stereo measurement of visible roof-edges.

3.2 Semi-Automatic Measurement of Visible Roof-Edges

In order to evaluate the proposed interactive scheme, we demonstrate three case studies using the above four-views aerial photos. Figure 5,6,7 depict those case studies with one flat roof and two gable roofs. Figure 8 illustrates the generated 3D building models.

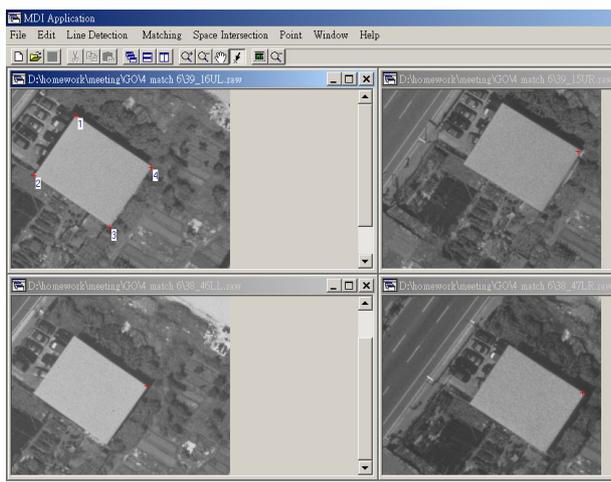


Figure 5. Case 1-Flat roof.

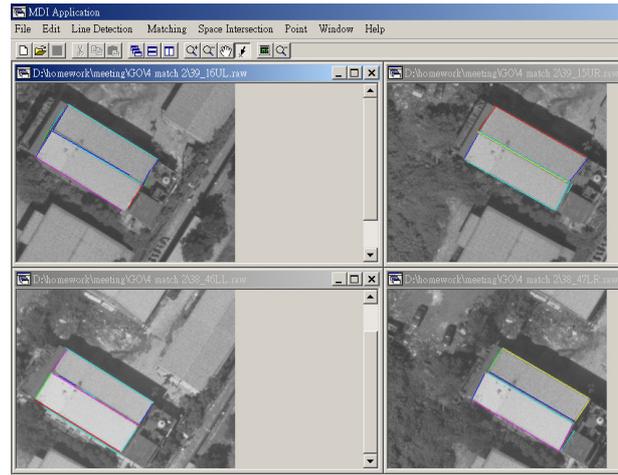


Figure 6. Case 2- Simple gable roof.

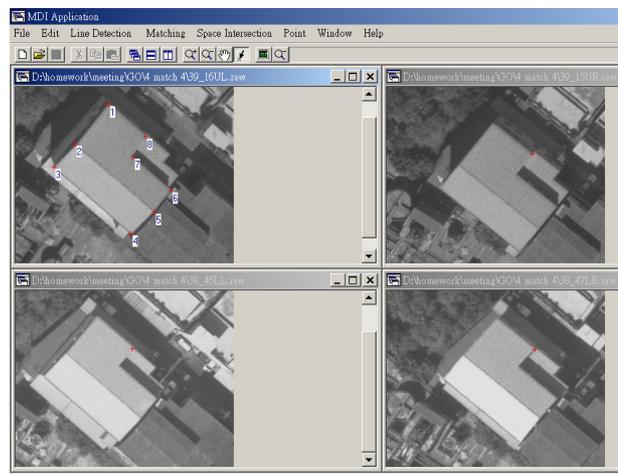


Figure 7. Case 3-Complex gable roof.

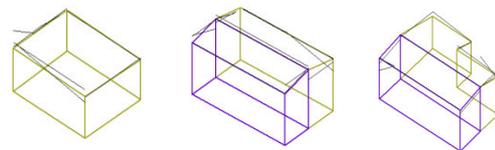


Figure 8. Reconstructed 3D building models.

3.3 Accuracy Assessment

The accuracy of the generated building models mostly depends on the accuracy of the measurements. For manual measurement, the total number of visible corners being evaluated is 163. After applying the SMS method for building modelling, it achieves a MEAN error of 1.06 cm, 1.22 cm, and 2.73 cm on the X, Y and Z-axis, respectively. In the mean time, a Root-Mean-Square Error (RMSE) of 13.5 cm, 14.5 cm, and 34.9 cm on the X, Y and Z-axis, respectively, is achieved. Since the original stereo-pair has a nominal ground sampling distance of 12.5 cm and a base-height-ratio of 0.3, the RMSE is close to be one pixel on the image scale, which falls into the range of random errors. It is proven that the proposed SMS method is accurate in 3D building modelling.

For semi-automatic approach, the feature line extraction and stereo matching will introduce a certain degree of error. For above three case studies, the overall accuracy is about 0.292 and

0.394 meters at horizontal plane and 0.577 meters at vertical axis. That means a 3-pixels of accuracy could be obtained using the simplest stereo-matching method. It demonstrates the potential and usefulness of an interactive scheme for 3D building modeling. However, a sophisticated stereo matching algorithm may get a better result.

4. CONCLUSIONS

This paper presents a novel method for geometrical building modeling based on an interactive scheme. The proposed Split-Merge-Shape method that adopts visible 3D roof-edges for building modeling is innovative. The major features of the proposed method are: (1) by means of the SMS technology, the integration of topographic mapping with 3-D building modeling is possible, (2) it avoids the hardware cost in stereo-measurement. A cost-effective environment could be established for 3-D mapping, and (3) it is proven to be robust, efficient, and with high accuracy.

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