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Semi-Automatic Approach for Building Reconstruction Using SPLIT-MERGE-SHAPE Method

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ABSTRACT: This paper proposes a novel method, which is called “SPLIT-MERGE-SHAPE”, for automatic structuring building model using 3D line segments. An initial cube, which covers all 3D line segments, is firstly drafted manually. Then, we “SPLIT” the cube using those 3D line segments to construct a combination of possible roof units. The next step is to “MERGE” every two neighbored roof units successively. Finally, in the 3D space, we “SHAPE” the roof by coplanar fitting. Experimental results show that the proposed method provides a sound solution for 3D building modeling. The method also minimizes human interventions especially when occlusions occur.

1. INTRODUCTION

1.1 Motivation and Purpose

According to the progress of computer technology, the establishment, management and application of city planning is toward to combine 3D city models in 3D Geographic Information Systems (GIS). Digital 3D city models are useful for simulation of noise, pollution, microclimate, and electro magnetic wave propagation for telecommunication. The models are also necessary for many applications, such as map revision, urban planning, and fly simulation, etc. The generation of reliable and accurate 3D city data is thus getting important.

There are four obligatory procedures in generating a 3D city model using digital photogrammetry, namely (1) image acquisition and aerial triangulation, (2) feature extraction and stereo measurements, (3) building model reconstruction or structuring, and (4) attribute assigning. Nowadays, the creation of 3D city data can be measured manually on an analytical stereo-plotter or a Digital Photogrammetry Systems (DPS). However, the process is time-consuming and labor intensive. In the creation of 3D building models, the operator is responsible for the measurements of 3D roof corners and building modeling. In dense urban areas, the buildings are connected to each other, thus the occlusion problems happen everywhere. When occlusions occur, the operator has to estimate the hidden corners from conjugate images. That procedure is tedious and limited to accuracy. The measurements of hidden corners and structuring of building models become critical in generating 3D city models for dense built-up areas.

1.2 Related Works

Since the demand of digital 3D city models is high in the future, traditional methods should be improved. In order to increase the efficiency for generating 3D city models, many investigations on building reconstruction based on semi-automatic or fully automatic approach have been presented in the past few years. Some brief descriptions about those related works are provided as follow.

Weidner[1997] and Haala & Brenner[1998] proposed to use Digital Surface Models (DSM) to reconstruct building models. The DSMs data can be generated automatically using digital aerial stereo-pairs or obtained from the Airborne Laser Scanning (ALS) [Lohr 1996]. The problem is that the precise building boundaries can't be well defined from the segmentation of DSMs. Thus, data from other sources are needed to assure the reconstruction.

Fischer et al. [1998] and Henricsson [1998] proposed a fully automatic approach for building reconstruction. In order to increase the accuracy and reliability of the results, they proposed to use multi-overlap aerial images. A critical step to realize the automation from 2D image is feature extraction. Some basic 2D image features maybe used directly for object modeling. Building objects, such as corners or roof patches, may further be modeled. Building hypothesis is created and verified by mutual interaction between 2D and 3D processes. However, successful feature extraction is relied on good image quality and visible image features. The generation of building hypothesis would be failed in dense built-up areas when building occlusions or shadow effects exist.

Gulch et al.[1999] proposed to use a single image and a building-based measurement for 3D city models generation. In the beginning, the operator is responsible for selecting an initial building type, and it will be projected on the image plane for user interaction. The operator has to adjust the location, the orientation, and the size of the building model, until it is well fitted on the building boundaries. For a complex building it could be decomposed into some basic building models and described by a Constructive Solid Graph (CSG)[Hoffmann, 1989]. The operator is responsible for handling of building structures too. Though the approach is innovative, the operator takes too much responsibility and thus a qualified operator is important.

Gruen & Dan [1997] proposed a model-based and semi-automatic approach. They used 3D point clouds to automated structuring building models. The 3D point clouds denote the roof corners including those hidden ones, which are measured manually. A pre-defined generic roof model database is used explicitly in the reconstruction process. One roof unit, which could be a complete roof or a roof part, is processed for each procedure. A K-parser is designed to classify the processed 3D point clouds into six generic roof models. A G-parser exploits geometric criteria to fit the planar faces and to enclose the 3D points as a complete CAD building model. One limitation of the approach is the structuring maybe failed if the processed roof is out of the pre-defined roof model database.

In this paper, we propose a novel method to reconstruct building models using 3D line segments. The main characters of the proposed "SPLIT-MERGE-SHAPE" method are (1) incomplete 3D line segments maybe used, (2) no pre-defined roof model database is needed, (3) user intervention is minimized, and (4) connecting buildings can be processed in a unified way.

2. THE SPLIT-MERGE-SHAPE METHOD

2.1 Assumption

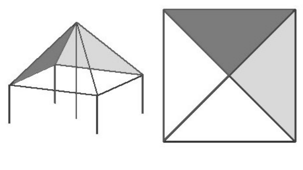
(a) (b)

Figure 1, A tetrahedron.

In the real world, it is difficult to describe all kinds of buildings using comprehensive building models. In our approach, a building model is decomposed into several roof units. A roof unit may be a part or a complete building. The roof units should be planar roof and its boundary projected on the ground is a polygon. One roof unit or a combination of roof units could be reformed into the polyhedral building models. In general, buildings may be represented by polyhedral model using planar roof faces and straight lines. For example, a perspective view of a tetrahedron is shown on Figure 1(a). From its ground projection, as shown on Figure 1(b), one can observe that the building is decomposed into four trihedrons. The boundary of each trihedron is a triangular on the ground. The three roof edges of the trihedron construct a coplanar roof.

The basic idea of the proposed method comes from the nature of "raining" and the "dripping eaves". Using a stereo-pair for ground feature delineation, only the visible objects can be directly measured. For building boundary delineation, those roofs that were occluded by higher roofs nearby cannot be measured. Those visible boundaries are identical to the "dripping eaves". Combing the waterfall from the "dripping eaves" with the roof surface the result is a polyhedron. The polyhedron is exactly the building model that we reconstruct. The nature of water falling from the "dripping eaves" realizes the idea of "splitting". The nature of "raining" is analogous to the "shaping" process.

2.2 Initialization

The key point to realize the whole method is to create an initial building model. The operator creates the initial building model by simply drafting a cube in 3D space, which covers all 3D line segments. The height of the cube could be assigned as any reasonable value.

2.3 Preprocessing

Due to manually measurement errors, some situations may happen, such as (1) two collinear lines maybe biased, (2) a rectangular building maybe skewed, and (3) two connected lines maybe intersected with overshooting. In addition, due to building occlusions or shadow effects, a long gap from a line terminal to an end wall may exist. Those problems should be solved in advance. The following preprocessing is optional depending on what kind of situation is dealing with.

2.3.1 Collinear Processing

In the splitting stage, two collinear-like lines will create an acute roof unit, which is not a reasonable building. Those acute roof units would not be merged or removed in the MERGE step. This situation could be avoided by using collinear processing. A collinear processing is to adjust the line parameter including slope and intercept.

2.3.2 Orthogonal Processing

Due to measurement error, a rectangular building may be skewed. One can rectify those buildings by the orthogonal processing. The orthogonal processing is to find those two orthogonal axes of all 3D line segments. Then, we enforce those 3D line segments to rotate and to align with those two principal axes.

2.3.3 Remove Dangle

Two connected line terminals should be jointed together as one point. Sometimes due to measurement error, those two lines maybe intersected to form small dangles. In the further MERGE process, those dangles maybe identified as legal 3D line segments. This situation will result illegal building outlines. Here we remove those dangles by changing the coordinates of those lines terminals to the intersecting ones.

2.3.4 Snap Dangle

Due to shadow effects or building occlusions, a long gap from line terminal to an end wall may exist. Theoretically, the proposed SPLIT-MERGE-SHAPE method could handle this situation. However, when dealing with a group of buildings, the long gap may be split and the corresponding roof unit may be merged with other roof unit. That will introduce illegal building models. The snap dangle processing, we extend the line terminals until it reach an end wall, is thus designed to avoid this situation.

2.4 SPLIT

The splitting process is working on the 2D horizontal plane. A 3D line segment is used as reference. If any roof units cover this reference 3D line segment then this procedure will split the roof unit into two. For successive 3D line segments it will construct a combination of possible roof units.

2.5 MERGE

The merging step is also working on the 2D horizontal plane. In the beginning, all roof units related to initial building model are removed. Then, two neighboring roof units are analyzed successively. If the shared boundary does not correspond to any one in those 3D line segments, those two roof units will be merged into one.

2.6 SHAPE

We assume that a roof unit has a coplanar surface with a polygonal outline on the ground plan. The shaping process is working on the 3D space. The initial step for shaping is to assign possible building height for roof edges from those 3D line segments. Then, a coplanar fitting is applied to each roof unit to finalize the building modeling.

3. CASE STUDY

Figure 2 shows the aerial photo for the case study. One can observe that some buildings are connected together. This situation causes many occlusions and shadow effects. Figure 3 shows the intermediate results of the proposed scheme. Figure 3(a) shows the original 3D line segments on the ground plane. The total number of 3D line segments is 58. Figure 3(b) shows the perspective view of those 3D line segments. Figure 3(c) depicts a draft of initial building model, which covers all 3D line segments. Figure 3(d) depicts the results of some preprocessing includes orthogonal processing, dangle removing and snapping. Figure 3(e) depicts the splitting result using the first 3D line, which split the initial building model into two roof units. Figure 3(f) shows the splitting result after using six 3D lines. Figure 3(g) shows the final splitting results. The total number of roof units is 129. Figure 3(h) removes those roof units that are related to the initial building model. Figure 3(i) shows the final results of merging in 2D space, while 3(j) is in a perspective view. One can observe that those roofs are in irregular shape. Figure 3(k) shows the first stage of shaping. Finally in figure 3(l), it shows the reconstructed building models. As depicted in dash-line circle, those occluded roofs are reconstructed. The total of process time from preprocessing to shaping is less than 2 seconds.

Figure 2, Case study area.

4. CONCLUSION

We have proposed a novel method for automatic structuring of building models using 3D line segments. The proposed method, which is called "SPLIT-MERGE-SHAPE", has the following advantages.

1. Without using roof model database, it is feasible to generic and complex building models especially in dense urban areas.
2. Without concerning those building occlusions, an operator is only needed to measure those 3D line segments that are visible. It reduces the operator's workload and increases the producing efficiency.
3. It copes with building corner occlusions and shadow effect problems.
4. It deals with a group of buildings in one procedure. A solution with higher generality is developed.
5. The user intervention is minimized that fits the idea of a semi-automatic approach.
6. The efficiency is high enough to establish an interactive system.

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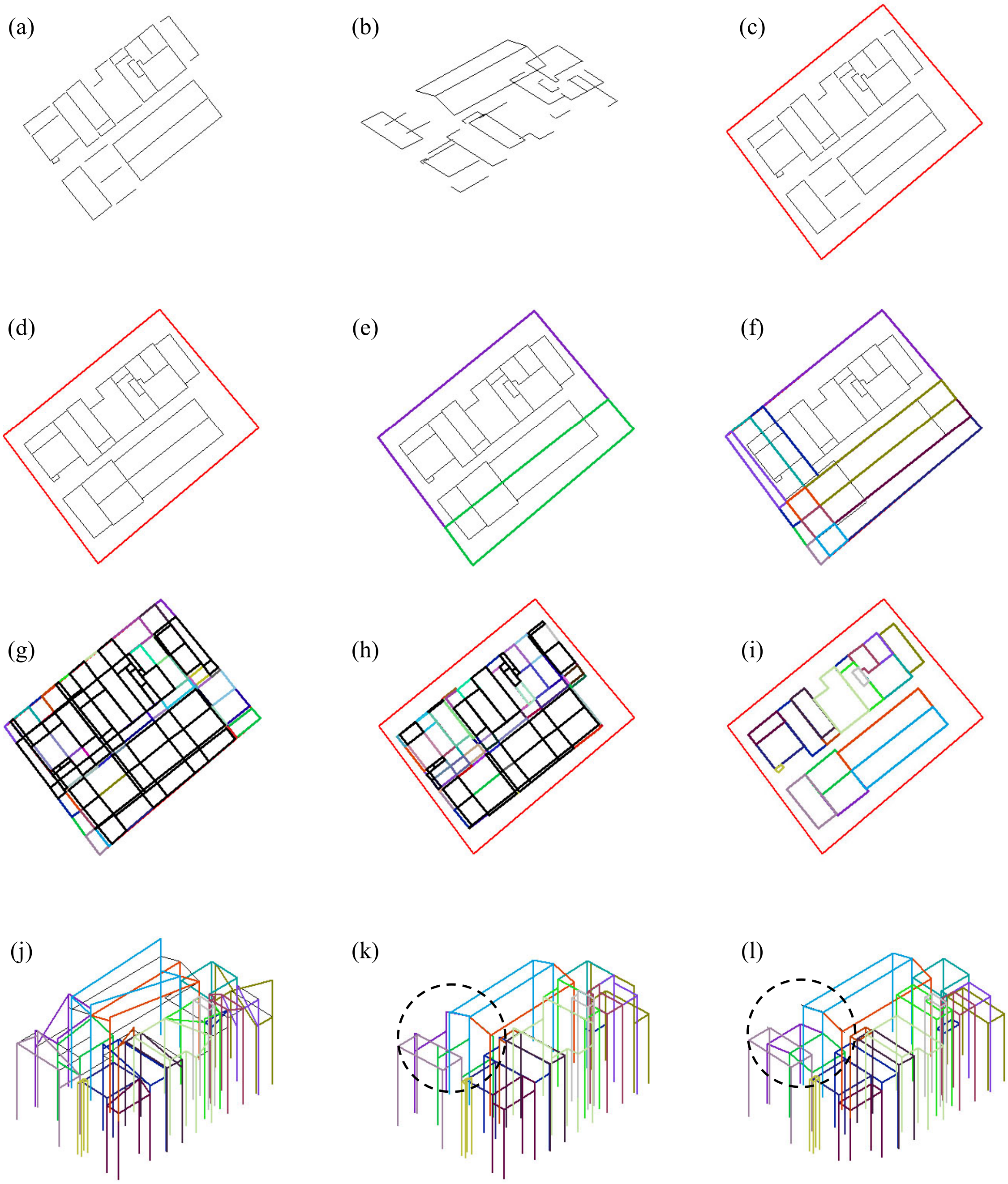

Figure 3, The intermediate results of the proposed scheme.