BUILDING RECONSTRUCTION FROM LIDAR DATA USING ITERATIVE REGULARIZATION APPROACH

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Abstract: This paper presents a scheme for the reconstruction of building models from LIDAR data by using an iterative regularization approach. The proposed scheme comprises three major parts: (1) elevation slicing, (2) boundary regularization, and (3) roof determination. The idea of elevation slicing is similar to the elevation contour map, where each contour line indicates a height level. We select a height interval and extract the building masks in different height levels, where each layer represents the building boundary with equal height. Then, the initial building boundaries are obtained by applying an edge detector. In the boundary regularization, we assume that the building boundaries have two dominant directions. We iteratively apply parallel and orthogonal constraints in building boundary regularization. In the roof determination, the line segments of each building are traced to form a polygon. Then, we shape the roof of each polygon from LIDAR point clouds. A TIN-based region growing is applied to extract the roof planes. The proposed method has been tested with LIDAR data of Hsin-Chu Science-based Industrial Park in northern Taiwan. Experimental results indicate that the proposed scheme reaches high reliability.
Keywords: LIDAR, Building, Reconstruction, Regularization.

1. Introduction

Building modeling in a cyber space is an essential task in the applications of three-dimensional Geographic Information Systems (GIS). This is especially true when a cyber city is to be established for urban planning and managements. Traditionally, the reconstruction of building models is performed by using aerial photography. As an emerging technology, the airborne LIDAR (LIght Detecting And Ranging) system provides a promising alternative. An airborne LIDAR integrates Global Position System (GPS) and Inertial Navigation System (INS), thus provides direct georeferencing capability. Its high precision in laser ranging and scanning orientation makes the decimeter accuracy for ground surface possible. The three-dimensional point clouds acquired by an airborne LIDAR system provide abundant shape information, thus, we propose here a novel scheme for building modeling.

There are two types of approaches in 3D building modeling, i.e., data-driven and model-driven [1]. Data-driven is a bottom-up strategy, which starts from extracts the building primitives such as building corner, building structure lines and building roof-tops. Then, group them into a building model through a hypothesis process [2]. On the other hand, model-driven is a top-down strategy, which starts with hypothesis of building model, then, verify the correctness of model in the existing data [3,4].

Several algorithms have been developed to reconstruct the building model from LIDAR data. For different data types, the strategy of building modeling can be classified into 3 categories. The first one uses the point data structure [5] to perform 3D Hough Transform to extract the building models from LIDAR point clouds. The second one applies the TIN data structure [6] to analyze the planar parameters. The third one follows the gird data structure [7] to group and linearize the building models based on pseudo-grid data.

Contour lines are widely used in traditional 2D topology maps. Each contour line indicates a height level in a 2D space. A contour line is an enclosed feature with a specific elevation. Hence, contour lines can be considered as a kind of line feature from terrain data. As LIDAR point clouds represent a terrain, we can generate the contour map from the point clouds. From the contour's point of view, we propose a new approach for the building modeling.

The LIDAR point clouds provide abundant shape information but lack break-lines information. Thus, the crucial issue of building modeling from the 3-D point clouds is to locate the building boundaries. Considering that most of the buildings are regular in shape, boundary regularization is an important step in building modeling for obtaining the optimal building boundaries. The boundary regularization constraint includes collinearity, orthogonal, symmetry and etc. The traditional least squares approach considers all the constraint simultaneously. The approach minimizes the error of the regularization condition. It provides the best fitting boundary without keeping regularity, i.e., orthogonality or parallelism. Hence, we propose a progressive regularization approach. It first groups the collinear building boundaries and then regularizes the perpendicular building boundaries.

The proposed scheme comprises three major parts: (1) elevation slicing, (2) boundary regularization, and (3) roof determination. The idea of elevation slicing is similar to the elevation contour map, where each contour line indicates a height level. We select a height interval and extract the building masks in different height levels, where each layer represents the building boundary with equal height. Then, the initial building boundaries in each building region are obtained by applying an edge detector. In the boundary regularization, we assume that buildings boundaries have orthogonal directions. We iteratively apply orthogonal and collinear constraints in building boundary regularization. In the roof determination, the line segments of each building are traced to form a polygon. Then, we shape the roof of each polygon from LIDAR point clouds. A TIN-based region growing is applied to extract the roof planes.

2. Building Detection

A region-based segmentation and object-based classification are integrated for building detection [8]. Both of the shape and attribute information are considered in the segmentation. Then, an object-based classification, instead of the pixel-based classification, is performed. Each region after segmentation is a candidate object for classification. An object-based classification considering the characteristics of elevation, texture, roughness, and shape is then performed to detect the building regions. After the building detection, each building region is isolated. The flow chat of building detection is shown in Fig. 1.

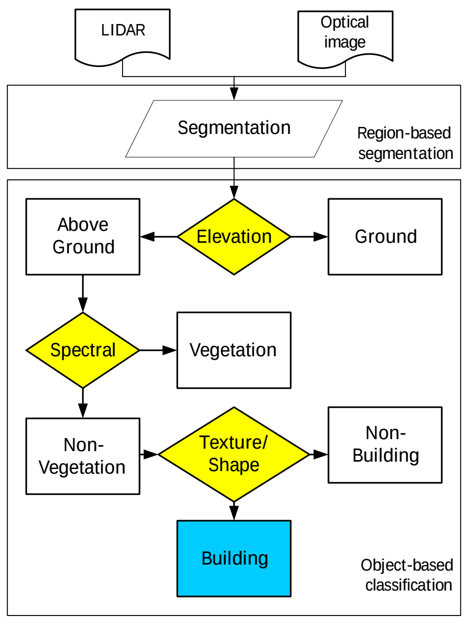


Fig 1. Flow chart of building detection

3. Building Reconstruction

After extracting the building regions, each individual building region is isolated. Then, we reconstruct the building model for each building region. The proposed method comprises essentially three parts. The first part involves the elevation slicing to obtain the building contour in different heights. The second part performs the boundary regularization to get the regular boundaries. The third one shapes the building roof-top by using a 3-D planes extraction. The schema of the proposed method is shown in Fig. 2.

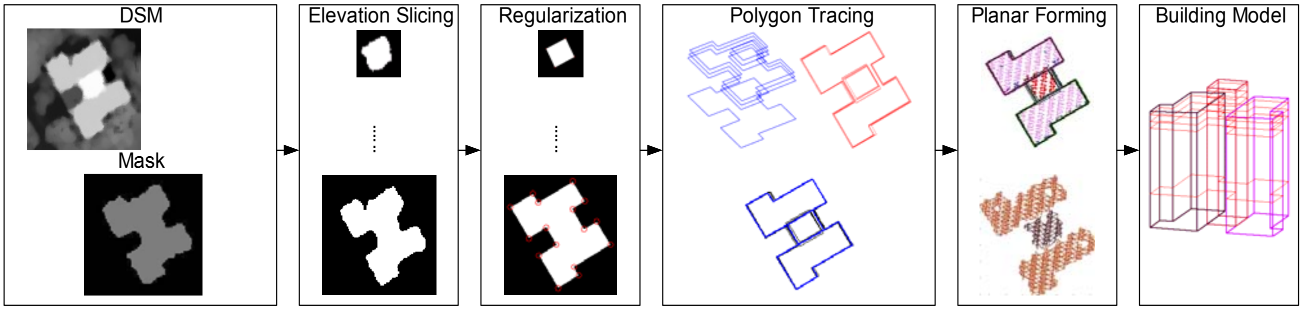


Fig 2. The schema of the building reconstruction

1) Elevation Slicing

The first stage of building reconstruction is to extract the contour lines from LIDAR data. We resample the discrete points from LIDAR data into regular grid as DSM. A TIN-based interpolation method is applied to rasterize the LIDAR point clouds. Then, we slice the DSM at a selected vertical interval to obtain contour lines for each building. The extracted contour lines represent the building boundaries at various height levels. The concept emulates that every building is built from base to top layer-by-layer. So, we analyze the building boundaries among layers. The steps of elevation slicing are illustrated in Fig. 3.

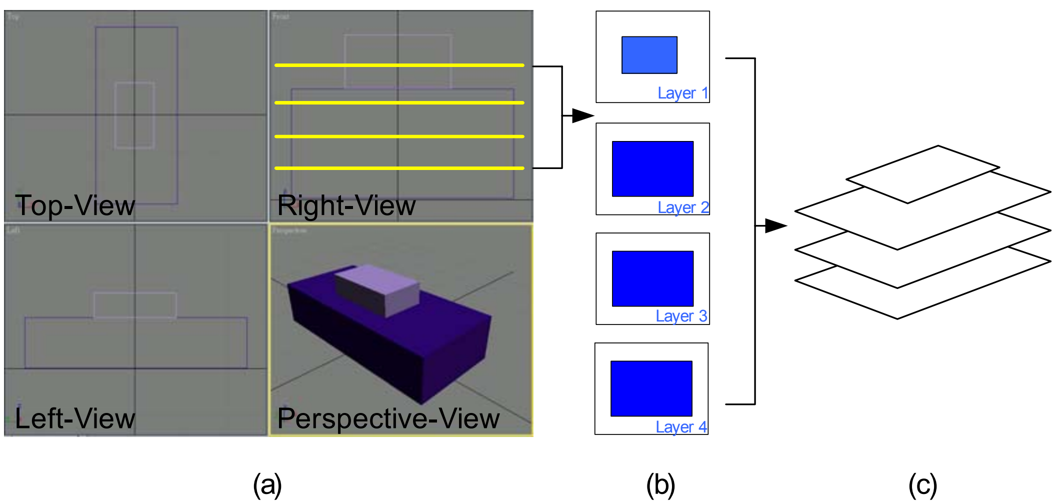
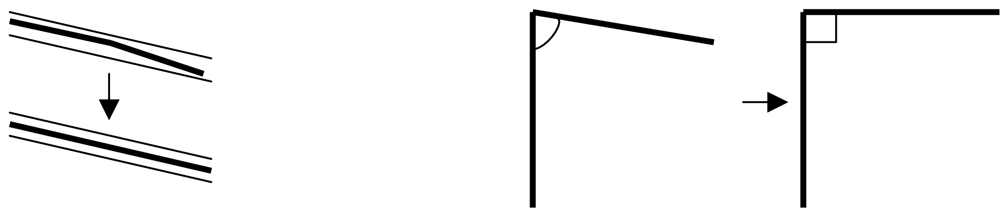


Fig. 3. Illustration of elevation slicing. (a) different views of an object. (b) individual slice. (c) stack all the slices

2) Boundary Regularization

After elevation slicing, we obtained building boundaries in different heights. However, those building boundaries are irregular in shape. So we perform the boundary regularization to adjust the building boundaries. In this stage, we assume that the building boundaries are orthogonal. It is observed that the base layer is never smaller than the top one. The boundary information of the base layer is always more sufficient than the top ones. Thus, the regularization starts form the base layer to the top one. The basic idea of boundary regularization is to iteratively keep each boundary collinear and adjacent boundaries orthogonal.

The building directions have to be determined at the beginning. We use the base layer to calculate those directions and apply them to all layers. We assume that the direction of longer line is the main building direction. So, this line segment represents the dominate direction of the building. Thus, the regularization process starts from the longer line. Then, collinear condition is applied to group the line segments. If the line segments are located in a pipeline buffer, those parallel lines are grouped into a new line. The new line is determined by a line regression process. Fig 4a shows the collinear process. In the next step, the orthogonal constraint is applied to obtain the perpendicular lines. Once the angle between lines met the orthogonal threshold, those lines are adjusted to be perpendicular. Fig 4b shows the orthogonalization process.



(a) (b)

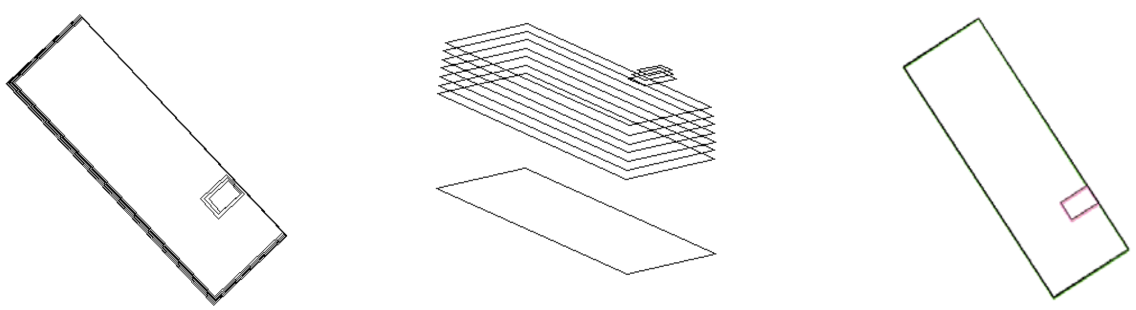
Fig. 4. Constrains of building boundary regularization. (a) collinearity, (b) orthogonal

3) Roof Determination

In the roof determination, the line segments of building boundary are traced to form a polygon. Then, we shape the roof of each polygon from LIDAR point clouds. There are two major steps in our schemes: (1) 2D polygon tracing, and (2) 3D planar patch forming.

1. 2D Polygon Tracing

The extracted straight line segments of building at various heights indicate the structure lines of building. Nevertheless, the structure lines may not be matched when the entire layers stack on a building footprint. In order to get the coincidence building footprint, we merge all the straight lines into the 2D plane. Then, we use a Split-Merge-Shape method [9] to group the straight lines into a polygon. An illustration of polygon tracing is shown in Fig. 5.



(a) **(b)** **(c)**

Fig. 5. Illustration of polygon tracing. (a) 2-D view of straight line segments at various heights,(b) perspective view of straight line segments at various heights, (c) results of polygon tracing

2. 3D Planar Patch Forming

The objective of 3D planar patch forming is to shape the roof-top of each polygon. We consider the LIDAR point clouds located in polygon to perform the 3D planar patch forming. A TIN-based region growing procedure is employed for 3D planes forming. The coplanarity and adjacency between triangles are considered for TIN-based region growing. Two coplanarity conditions are considered for merging triangles: (1) the angle between normal vectors for neighboring triangles, and (2) the height difference between triangles. When the triangles meet the coplanarity criteria, the triangles are merged together as a new plane. Fig. 6 shows the coplanarity condition between triangles. Once the planar segments are extracted, we use least squares regression to determine the coplanarity function of planar segment. Thus, we use the 3D plane information to define an appropriate roof. The plane equation is presented by Eq.1. Fig. 7 illustrates the 3D planar patch forming for building modeling.

$$Z=aX+bY+c \tag{1}$$

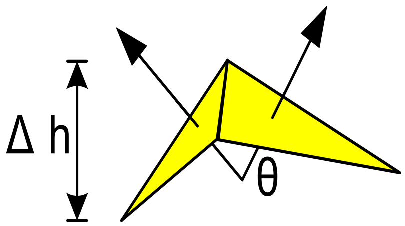


Fig. 6. Illustration of coplanarity condition

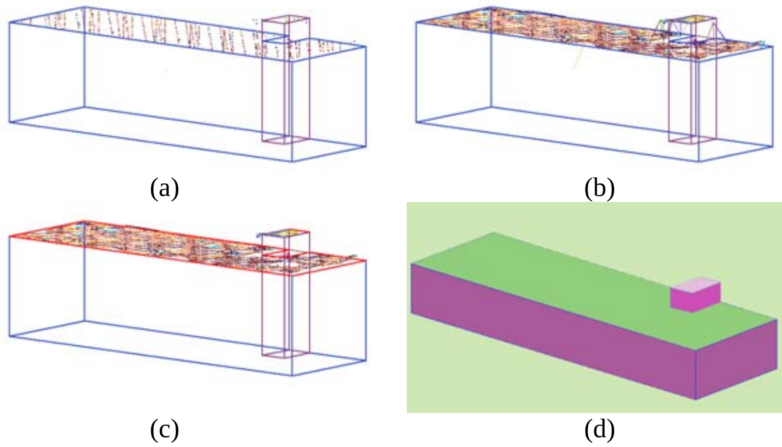


Fig. 7. Illustration of 3D planar patch forming, (a) point clouds in polygon. (b) triangular form in polygon. (c) extracted 3D planar facets. (d) generated building model

4. Experimental Results

The LIDAR data used in this research cover an area in Hsin-Chu Science-based Industrial Park of north Taiwan. Fig. 8 shows the image of test area. The data was obtained by a Leica ALS 40 system. The average density of LIDAR data is 1.6 pts/m^2. The discrete points LIDAR points are rasterized to DSM with a pixel size of 0.5m. The DSM is shown in Fig. 9.

Fig. 8. Aerial image of test area

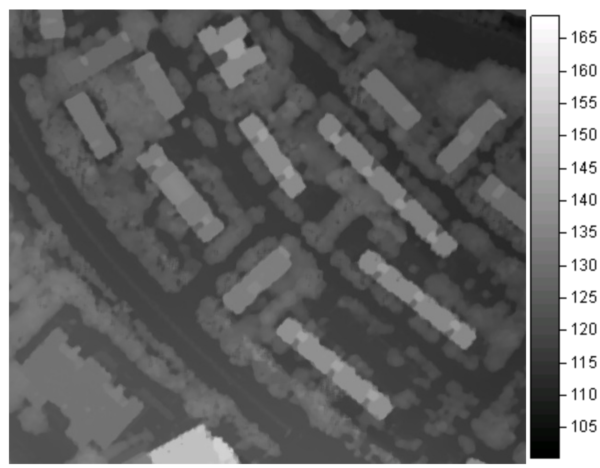


Fig. 9. Digital surface model

There are 13 buildings in the test area. Notice that the non-building regions are removed after the building detection process. For each building region, we generated the contour map with a 2m height interval. The contour map is shows in Fig. 10. Through the boundary regularization process, each contour line is regular. After that, those regular boundaries are traced as building polygons. Fig. 11 demonstrates the building footprints. The 3D planes are extracted by TIN-based region growing. The building roof-top can be reconstructed by the 3D planes. Comparing the roof-top planes in the reconstructed models with the LIDAR point clouds, the RMSE of shaping error is 0.60m. The results of building models are shown in Fig. 12.

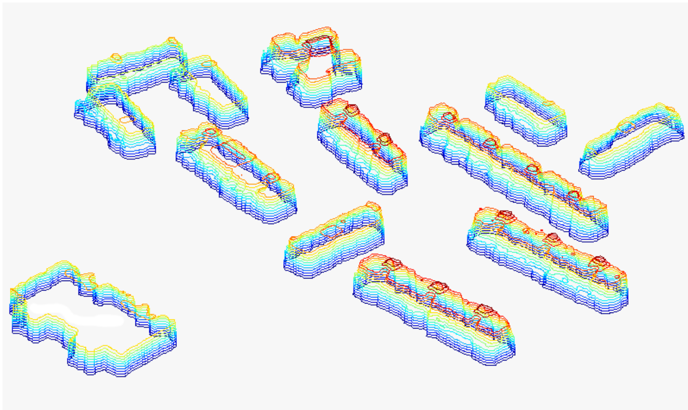


Fig. 10. Results of elevation slicing

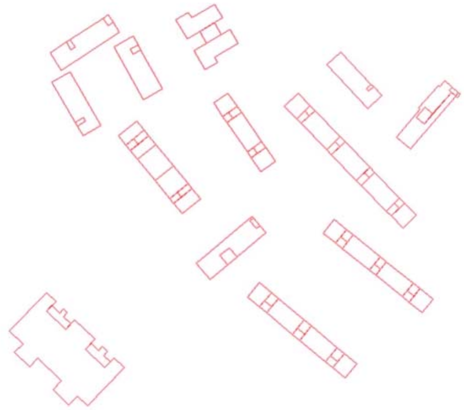


Fig. 11. Results of regularization

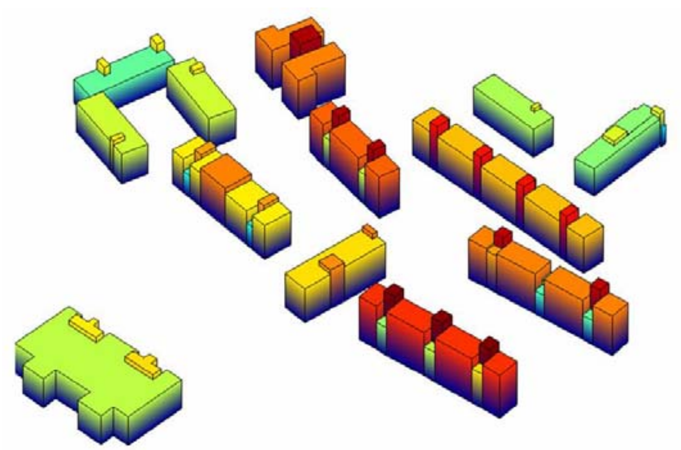


Fig. 12. Perspective view of the generated building model

5. Conclusions

In this investigation, we have presented a scheme for the reconstruction of building models by performing an interactive regularization approach. The results from the test demonstrate the potential of the automatic method for building reconstruction. The shaping error of reconstructed building models is better than sub-meter. The improvements of the scheme for treating more complex buildings are the major works in the future.

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