Building Reconstruction from LIDAR Data and Aerial Imagery

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Abstract- This paper presents a scheme for building detection and reconstruction by merging LIDAR data and aerial imagery. In the building detection part, a region-based segmentation and object-based classification are integrated. In the building reconstruction, we analyze the coplanarity of the LIDAR point clouds to shape roofs. The accurate positions of the building walls are then determined by integrating the edges extracted from aerial imagery and the plane derived from LIDAR point clouds. The three dimensional building edges are thus used to reconstruct the building models. In the reconstruction, a patented method SMS (Split-Merge-Shape) is incorporated. Having the advantages of high reliability and flexibility, the SMS method provides stable solution even when those 3D building lines are broken. LIDAR data acquired by Leica ALS 40 and aerial images were used in the validation. Experimental results indicate that the successful rate for building detection is higher than 81%. The positioning for buildings may reach sub-meter accuracy.

I. 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, while aerial images include plentiful spectral information. Thus, the integration of those two complementary data sets reveals the possibility for automatic building reconstruction. From data fusion’s point of view, we propose here a scheme to automatically reconstruct building models using aerial images and LIDAR point clouds.

Several data fusion algorithms have been developed to reconstruct the building model, e.g., LIDAR and aerial images [1], LIDAR and three-line-scanner images [2], LIDAR and high satellite images [3], LIDAR, aerial images and 2D maps [4]. In this paper, we present a new scheme to reconstruct buildings. The proposed scheme comprises two major parts: (1) building detection, and (2) building reconstruction. Spatial registration of LIDAR data and aerial imagery is performed as data preprocessing. The registration is done in such a way that two data sets are unified in the object coordinate system. Meanwhile, we recover the exterior orientation parameters of the aerial imagery by employing ground control points. Then, a region-based segmentation and object-based classification are integrated in the stage of building detection. In the segmentation for surface elevation, the LIDAR points are resampled to raster form, the color aerial image is also applied in this stage to include the spectral information. Then, a developed object-based classification method detects building regions considering spectral, shape, texture, and elevation information. In the stage of building reconstruction, building blocks are divided and conquered. Once the building regions are detected, we analyze the coplanarity of the LIDAR point clouds to shape the roofs. Then, the scheme performs TIN-based region growing to generate 3D planes for each building region. The edges extracted from aerial images are incorporated to determine the 3-D position of the building walls. A patented method SMS [5] is then employed to generate building models in the last step. Having the advantages of high reliability and flexibility, the SMS method provides stable reconstruction even when those 3D building lines are broken.

II. BUILDING DETECTION

The objective of building detection is to extract building regions. There are two steps in the proposed scheme: (1) region-based segmentation, and (2) object-based classification. The flow chart of building detection is shown in Fig. 1.

A. Region-based Segmentation

There are two ways to do the segmentation. The first one is the contour-based segmentation. It performs the
segmentation by using edge information. The second one is the region-based segmentation. It uses a region growing technique to merge pixels with similar attribute [6]. We select the region-based segmentation because its noise tolerance is higher than contour-based approach. The proposed scheme combines elevation from LIDAR data and spectral information from orthoimages in the segmentation. The pixels with similar geometric and spectral properties are merged into a region.

We use the Grey Level Co-occurrence Matrix (GLCM) to analyze image texture. GLCM is a matrix of relative frequencies for pixel values occurred within a specific neighboring. We select the entropy and homogeneity as indices to quantify the co-occurrence probability. The role of texture information is to separate the building from vegetation when the objects have similar spectral response.

4) Roughness: The roughness of LIDAR data aims to differentiate the vegetation regions and non-vegetation ones. The surface roughness is similar to the texture information of image data. The role of surface roughness is to separate the building and vegetation when the objects have similar spectral response. We select the variance of slope as the roughness index.

5) Shape: The shape attribute includes size and length-to-width ratio. An area threshold is used to filter out those over-small objects. That means the regions smaller than a minimum area are not taken into account as a building. The length-to-width ratio is suitable to remove those over-thin objects. The objects would not be considered as a building when the length-to-width ratio is larger than a threshold.

III. BUILDING RECONSTRUCTION

The reconstruction stage begins when each individual building region is isolated. The stage includes four parts: (1) 3D planar patch forming, (2) initial building edge detection, (3) straight line extraction, and (4) shaping.

A. 3D Planar Patch Forming

The first part of building reconstruction is to extract the 3D planar patches from LIDAR data. A TIN-based region growing procedure is presented for the plane forming. Neighboring triangles are combined when the coplanarity condition is fulfilled. Two factors 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 as a same plane. Once the planar patches are extracted, we use least squares fitting to determine the coplanarity function of the planar patch. Fig. 2 illustrates the forming for planar patches.

B. Initial Building Edge Detection

After extracting the 3D planes, we detect the initial building edge from the rasterized LIDAR data. The initial edges in each building region are obtained by applying a Canny operator [8]. We set a length threshold to remove short lines. Then, we include the elevation information of edge to perform the 3D line tracking. Each line is associated with a 3D planar patch as stated. The steps of initial building edge extraction are illustrated in Fig. 3.

C. Straight Lines Extraction

Based on the initial edges, the precise building edges are to be extracted in the image space. The rough edges from

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**Figure 1. Flow chart of building detection**

**B. Object-based classification**

After the segmentation, 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, spectral information, texture, roughness, and shape is performed to detect the building regions [7]. The characteristics are described as follow:

1) Elevation: Subtracting DTM from DSM, we generate the normalized DSM (nDSM). The data describes the height variations above ground. Setting an elevation threshold one can select the objects above ground. The above ground surface includes building and vegetation.
2) Spectral information: The spectral information comes from color aerial images. A greenness index is used to distinguish vegetation from non-vegetation areas.
3) Texture: The texture information comes from aerial images.
4) Roughness: The roughness of LIDAR data aims to differentiate the vegetation regions and non-vegetation ones. The surface roughness is similar to the texture information of image data. The role of surface roughness is to separate the building and vegetation when the objects have similar spectral response. We select the variance of slope as the roughness index.
5) Shape: The shape attribute includes size and length-to-width ratio. An area threshold is used to filter out those over-small objects. That means the regions smaller than a minimum area are not taken into account as a building. The length-to-width ratio is suitable to remove those over-thin objects. The objects would not be considered as a building when the length-to-width ratio is larger than a threshold.

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LIDAR data are used to predict the location of the straight lines in the image space. Through the Hough Transform [9], image straight lines around the predicted area are detected. Given the image coordinates and the height information from 3D planes, we can calculate the 3D edges in the object space by employing exterior orientation parameters. Fig. 4 is an example of straight lines extraction.

D. Split-Merge-Shape Building Modeling

The extracted 3D edges are processed by a patented method, i.e., Split-Merge-Shape, SMS for building reconstruction. 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. Fig. 5 is the illustrates the SMS building modeling.

IV. EXPERIMENTS

The LIDAR data used in this research cover an area in Hsin-Chu Science-based Industrial Park of north Taiwan. The data was obtained by a Leica ALS 40 system. The discrete LIDAR points has been classified into ground points and surface points. The average density of LIDAR data is 1.6 pts/m². The ground sampling distance of aerial image is 0.1m. Fig 6 shows the image of test area.

In building detection, the surface points and ground points from LIDAR data are rasterized to DSM and DTM both with a pixel size of 0.5m. The aerial image is orthorectified by using the LIDAR DSM. The classification result is shown in fig. 6. A 1/1000 scale topographic map was used as a ground truth. The map is shown in Fig. 7. It is found that 79 out of 98 buildings are successfully detected. The detection rate is 81%. The missing buildings are, in general, small
ones. Ten missing buildings are smaller than 35 m². It is also observed, due to the time difference between the test data and the topomap, 5 buildings in the map are temporary ones that do not appear in the aerial photo.

In the building reconstruction, fig 9 illustrates building models that are used in the accuracy evaluation. In the accuracy validation, we compare the coordinates roof corners in the reconstructed models with the corners acquired from the ground truth. The root mean square errors are 0.45m, 0.56m, 0.70m in the X, Y, Z directions, respectively.

IV. CONCLUSIONS

In this investigation, we have presented a scheme for the extraction of building regions and building modeling by merging of LIDAR data and aerial imagery. The results from the test demonstrate the potential of the automatic method for building reconstruction. More than 81% buildings region are correctly detected by our approach. Notice that most of the missing buildings are very small. Some of them are even temporary ones. If the density of LIDAR points increases, higher detection rate may be expected. The building models generated by the proposed method take the advantage of high horizontal accuracy from aerial images and high vertical accuracy from LIDAR data. The reconstruction buildings models may reach sub-meter accuracy.

REFERENCES