AUTOMATIC IDENTIFICATION OF ROOF TYPES AND ROOF MODELING USING LIDAR

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ABSTRACT:

This paper presents a method for point-based 3D building reconstruction using LiDAR data and digital map. The proposed method consists of three processes: extraction of building roof points, identification of roof types, and 3D building reconstruction. After extracting points inside the polygon of building, the ground surface, wall and tree points among the extracted points are removed through the filtering process. The filtered points are then fitted into the flat plane using ODR(Orthogonal Distance Regression). If the fitting error is within the predefined threshold, the surface is classified as a flat roof. Otherwise, the surface is fitted and classified into a gable or arch roof through RMSE analysis. Based on the roof types identified in automated fashion, the 3D building reconstruction is performed. Experimental results showed that the proposed method classified successfully three different types of roof and that the fusion of LiDAR data and digital map could be a feasible method of modelling 3D building reconstruction.

KEY WORDS: LiDAR, Building reconstruction, 3D modelling, Roof type

1. INTRODUCTION

LiDAR System acquires 3D point data through scanning ground surface with laser. LiDAR data which is irregular point cloud directly has x,y,z information of a ground point. It is possible to generate 3D models of building with point data but it is difficult to extract outline of building.

The researches of 3D building reconstruction had proceeded for last few years (Vosselman and Dijkman, 2001; Overby et al, 2004). 3D building modeling using LiDAR data generally path through two stages. First is separating segments of building from LiDAR data. Second, reconstructing building using building points proposed which are segmented in first step. The studies of filtering method extracting building point proposed are advanced. Choi(2004) ended up good results with LiDAR data of simple region, on the other hand bad results in complicated region. Hence they suggested the necessity of an advanced algorithm suitable for complicated region as central city.

Therefore the purpose of this study extracts building points proposed from LiDAR data through overlapping analysis using digital map and LiDAR data and automatically identify roof type with building points and propose 3d building modeling algorithm by roof type.

The study automatically identifies roof type of buildings with simple roof and proposes a method of roof modeling suitable for classified roof. Fig-1 represents an outline of this study.

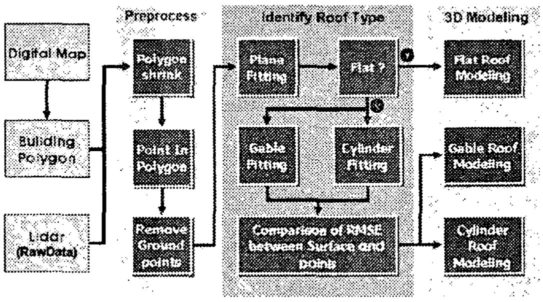


Fig-1. Study flow chart

2. 3D BUILDNIG MODELING

2.1 Preprocessing

The building points proposed were extracted by overlapping Building polygon in Digital map and original LiDAR data. Partial ground, tree, walls points are possible to include in the extracted building points. So roof points of building are separated from those points by the filtering (Choi, 2004).

2.2 Identification of roof type

The roof of complex building composed of simple roofs (flat, gable, cylinder) such as Fig-2. And if roof types of a building are identified, each roof is modeling by roof type. After all, a building is completely reconstructed as compounding modeled roofs.

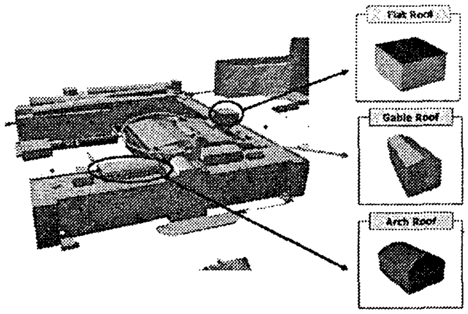


Fig-2. Roof type of complex building

The identification of roof type progresses to three steps. Firstly carry out flat fitting with building points and calculate RMSE which is Root Mean Square of distances from building points to a plane. If RMSE is less than an allowable error, building points are classified as those of flat roof. Otherwise, try to do gable fitting and cylinder fitting. When RMSE calculated by gable fitting is more than RMSE by cylinder fitting, building points are classified as cylinder roof. Contrary result, building points are classified as gable roof.

2.2.1 Flat fitting : Defining optimal plane with a number of points is generally Least Squares Method (LSM). LSM is fitting method which root mean square of distances from a plane to points has to minimize. Generally speaking, distance is a difference of z-value between plane and points. It has to consider orthogonal distance between plane and points to apply LSM to 3D model fitting. Orthogonal distance is a minimum distance from model to points. This study applies ODR (Orthogonal Distance Regression) to flat fitting. After fitting by ODR, estimate through a difference between RMSE calculated by an estimated plane and an allowable error. That is, if estimated RMSE is less than a threshold, points used in fitting are building points of flat roof. Fig-3 is line and plane fitted by ODR.

Equation(1) si RMSE about distance between estimated plane $(ax+by+cz=0)$ and points (x_i, y_i, z_i).

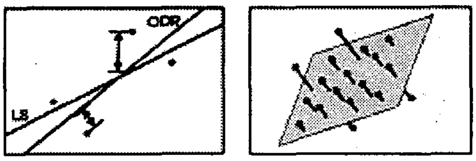


Fig-3. LS and ODR line fit(left), ODR plane fit(right)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}[(ax_i+by_i+cz_i+d)^2/(a^2+b^2+c^2)]}{n}} \quad (1)$$

If both horizontal error and vertical error of original LiDAR data are zero, RMSE is also zero. Because LiDAR data actually includes to errors, an allowable error is decided in due consideration of vertical error, horizontal error just as Fig-4. Accordingly an allowable error defines as equation(2).

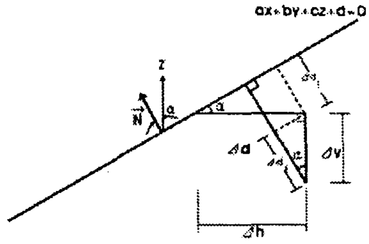


Fig-4. Distance error

$$\Delta d = \Delta d_1 + \Delta d_2 = \Delta h \cdot \sin\alpha + \Delta v \cdot \cos\alpha \quad (2)$$

Where, Δh and Δv are horizontal error and vertical error. And α is an angle between normal vector of plane and z-axis. If RMSE is less than a threshold $(\Delta d \times 2)$, points are on a plane.

2.2.2 Gable fitting : Building points on gable roof must be grouped into two roof patches. Firstly we decides minimum area square (MAS) which includes every points and continuously divide into quad-tree. To merge separated quad easily in using sequence search, we use pseudo-grid which Jhwa(2003) proposed. Each point which is included in a quad is given a property of quad and divided into pseudo-grid.

Because LiDAR data has vertical error, two divided quads are such as picture-5 in critical case. If an angle between the normal vectors of two quads is less than the result of equation(3), two quads are merged because two planes are same.

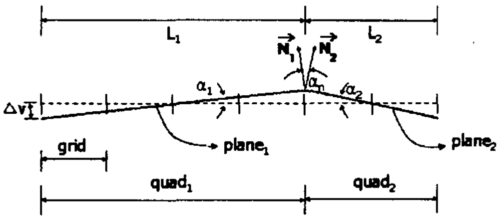


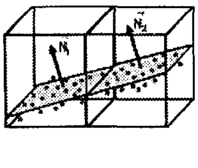
Fig-5. Plane angle criteria

$$\alpha_n = \alpha_1 + \alpha_2 = \tan^{-1}\left(\frac{2\Delta v}{L_1}\right) + \tan^{-1}\left(\frac{2\Delta v}{L_2}\right) \quad (3)$$

Where L_1, L_2 = the size of Quad

Δv = vertical error

The same planes are merged just as Fig-6 through the plane angle and height of a grid, and the surface of gable roof is composed. Fig-7 shows that roof patches are different although the normal vectors of a grid are equal. The condition of a same roof patch is continuity. If a roof patch has discontinuity, it has to be divided into two parts. Also when the height difference of boundary points adjacent to each grid must be less than allowable value, roof patches are merged. The height threshold is $2\times\Delta v$ considered vertical error.



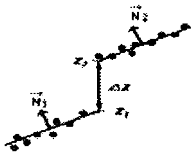


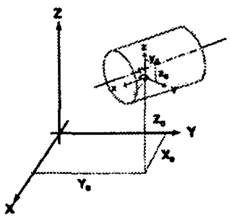
Fig-6. Merge process   Fig-7. Height criteria

2.2.3 Cylinder fitting : Arch roof represents a cylinder that is truncated in the axis-direction of it. Fitting method fits a cylinder which makes a minimum distance between roof points and the surface of it and we find out the parameters of it. When almost all of the arch roofs are modeled the shape of cylinder, the axis is parallel with the X-Y plane. Therefore we take into account the kappa of rotation parameters the transformation to model coordinate system.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R_k \begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix} \tag{4}$$

If the X-axis of model coordinates system is parallel with the center axis of cylinder such a Fig-8, a shape projected every point of model coordinate system to Y-Z plane is circle just as Fig-9.

$$(y - y_0)^2 + (z - z_0)^2 = C_r^{\,2} \tag{5}$$



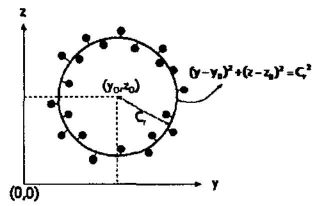


Fig-8. Cylinder fitting   Fig-9. Circle fitting

The parameter of cylinder is $\vec{a} = [y_0 \quad C_r \quad \kappa]^T$ and the distance between a building point (y_i, z_i) and a surface of cylinder is equation(6) (R.R. Dharma,2001).

$$D_i = \sqrt{(y_i - y_0)^2 + (z_i - z_0)^2} - C_r \tag{6}$$

F is non-linear in $F = D^2$. Therefore equation(6) is linearized to Taylor Series.

$$0 = F = F_0 + \frac{\partial F}{\partial a}\Delta a = F_0 + \frac{\partial F}{\partial y_0}\Delta y_0 + \frac{\partial F}{\partial z_0}\Delta z_0 + \frac{\partial F}{\partial C_r}\Delta C_r + \frac{\partial F}{\partial \kappa}\Delta \kappa \tag{7}$$

Differential parameters are

$$\frac{\partial F}{\partial y_0} = 2D_i \frac{\partial D_i}{\partial y_0} = \frac{D_i}{\sqrt{d_i}}\frac{\partial d_i}{\partial y_0}, \quad \frac{\partial F}{\partial z_0} = 2D_i \frac{\partial D_i}{\partial z_0} = \frac{D_i}{\sqrt{d_i}}\frac{\partial d_i}{\partial z_0}$$

$$\frac{\partial F}{\partial C_r} = 2D_i \frac{\partial D_i}{\partial C_r} = \frac{D_i}{\sqrt{d_i}}\frac{\partial d_i}{\partial C_r}, \quad \frac{\partial F}{\partial \kappa} = 2D_i \frac{\partial D_i}{\partial \kappa} = \frac{D_i}{\sqrt{d_i}}\frac{\partial d_i}{\partial \kappa} \tag{8}$$

Where $d_i = (y_i - y_0)^2 + (z_i - z_0)^2$

Equation(8) is represented by equation(9) again.

$$\frac{\partial F}{\partial y_0} = \frac{2D_i}{\sqrt{d_i}}(y_0 - y_i), \quad \frac{\partial F}{\partial z_0} = \frac{2D_i}{\sqrt{d_i}}(z_0 - z_i)$$

$$\frac{\partial F}{\partial C_r} = \frac{2D_i}{\sqrt{d_i}}(-1), \quad \frac{\partial F}{\partial \kappa} = \frac{2D_i}{\sqrt{d_i}}(y_i - y_0)x_i \tag{9}$$

The observation equation(F) is

$$0 = D_i^2 + 2D_i\left[\frac{(y_0 - y_i)}{\sqrt{d_i}}\Delta y_0 + \frac{(z_0 - z_i)}{\sqrt{d_i}}\Delta z_0 - \Delta C_r + \frac{x_i(y_i - y_0)}{\sqrt{d_i}}\Delta\kappa\right]$$

$$\frac{-D_i}{2} = \frac{(y_0 - y_i)}{\sqrt{d_i}}\Delta y_0 + \frac{(z_0 - z_i)}{\sqrt{d_i}}\Delta z_0 - \Delta C_r + \frac{x_i(y_i - y_0)}{\sqrt{d_i}}\Delta\kappa \tag{10}$$

Let equation(10) represent in Matrix

$$\begin{bmatrix} \frac{y_0 - y_i}{\sqrt{d_i}} & \frac{z_0 - z_i}{\sqrt{d_i}} & -1 & \frac{x_i(y_i - y_0)}{\sqrt{d_i}} \end{bmatrix} \begin{bmatrix} \Delta y_0 \\ \Delta z_0 \\ \Delta C_r \\ \Delta\kappa \end{bmatrix} = \begin{bmatrix} -\frac{D_i}{2} \end{bmatrix} \tag{11}$$

We can reconstruct a cylinder with the parameters of cylinder $\vec{a} = [y_0 \quad z_0 \quad C_r \quad \kappa]^T$

2.3 3D Modeling of roof

Building is composed of roof and wall. Therefore building is reconstructed with roof planes extracted previous step and building outlines of digital map.

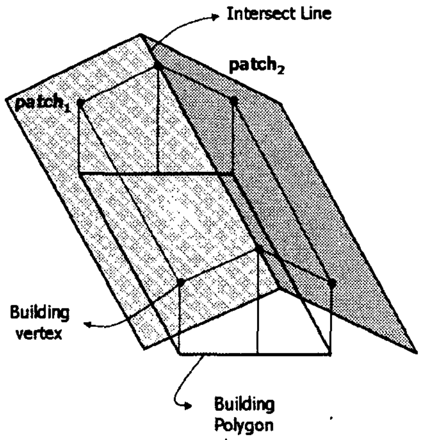


Fig-10. Merge process

3. TEST AND RESULT

3.1 Test data and test building

LiDAR data acquired over Inha Uniersity and surveying fight were carried out in July 2004 with ALTM 3070 of Optech. Also we use 1/1000 digital map of same region. We make a choice buildings covered the simple roof in Inha University.

Table 1. Test building

Building	Roof type
Seoho kwan	Flat(3 pathces)
2 ho kwan	Arch (4 patches)
5 ho kwan	Arch
Jeongsuk kwan	Arch
4 ho kwan	Gable
Gosok lab.	Gable

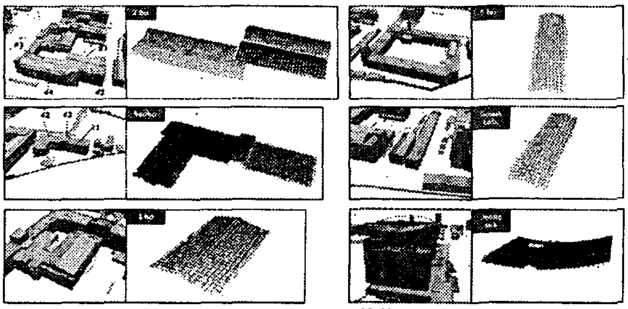


Fig-11. Test building

3.2 Test and results

The threshold of planarity (0.3m) was applied to the vertical and horizontal error of used LiDAR data. And if RMSE is less than the threshold, we assumed that building points are on a plane. Otherwise we tested both the gable fitting and the cylinder fitting. As a result, assumed roof type is correctly accorded with real roof type. Buildings are reconstructed with equations of roof plane and parameters of cylinder by roof type.

Table 2. Assumption roof type for RMSE

Building	Distance RMSE (m)			Assume	Real
	Flat	Gable	Arch		
Seoho #1	0.11226	-	-	Flat	Flat
Seoho #2	0.11078	-	-	Flat	Flat
Seoho #3	0.12313	-	-	Flat	Flat
5ho	0.82145	0.34143	0.29951	Arch	Arch
2ho #1	0.63924	0.22435	0.16805	Arch	Arch
2ho #2	0.81700	0.26151	0.16672	Arch	Arch
2ho #3	0.55818	0.19611	0.13886	Arch	Arch
2ho #4	0.63523	0.19965	0.11495	Arch	Arch
Jeongsuk	6.88097	0.33739	0.25226	Arch	Arch
4ho	0.60002	0.21594	0.22870	Gable	Gable
Gosok Lab.	0.59203	0.24703	0.28751	Gable	Gable
Threshold = 0.3m					

4. CONCLUSION

This paper described an automatic approach based on point for building reconstruction and identification of roof type from LiDA data. As the result of test, the accuracy of roof identification was 100%. The result showed that our approach has really good performance. This approach has potential for practical use in GIS. With the available of more building outline and dense LiDAR data, the attached building such as chimney or penthouse etc. also can be constructed. This approach has significance for economical acquisition 3D spatial data through data fusion of digital map and LiDAR.

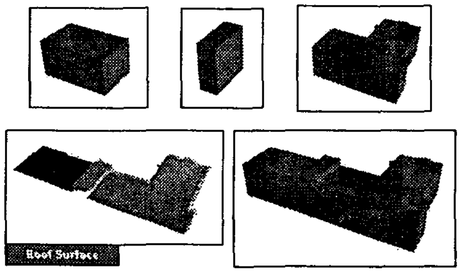


Fig-12. Flat roof modeling

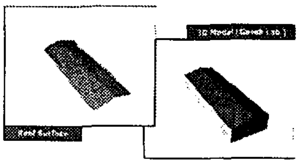


Fig-13. Gable roof modeling

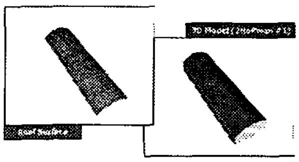


Fig-14. Arch roof modeling

ACKNOWLEDGEMENT

This research was supported by the MIC(Ministry of Information and Communication), Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute of Information Technology Assessment)

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