AUTOMATIC RECONSTRUCTION OF 3D CITY FROM LIDAR POINT CLOUD DATA

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ABSTRACT

The demand of 3D city model has been increasing in a wide range of applications, such as urban planning, computer gaming with realistic city environment, car navigation system with showing 3D city map, and others. We proposed a simple method for reconstructing a 3D city model from airborne LiDAR point cloud data. The proposed method was implemented by computing connected regions from altitude mask images and by assigning their altitude averaged over corresponding region in the gray scale LiDAR image. The altitude mask images are generated from the gray scale LiDAR image with certain threshold ranges of the altitude. We demonstrated in this study how to reconstruct a 3D Kanazawa railway station area by using the airborne LiDAR point cloud data.

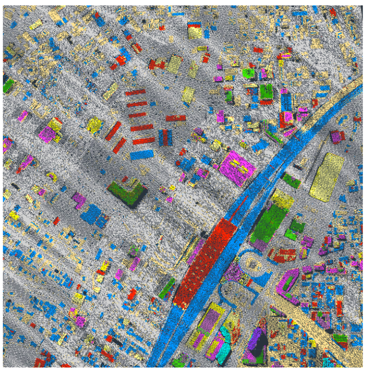
Keywords: Automatic Reconstruction, 3D City Model, Gray Scale LiDAR image

INTRODUCTION

With the emergence of the airborne laser scanning technology (known as LiDAR: Light Detection and Ranging), we are able to have a rapid and accurate collection of 3D positional data over an extended area. However, while we have LiDAR point cloud data with accurate 3D positional information, we still have a major problem on the automatic transformation from 3D LiDAR data to a 3D model and it is one of hot research topics (Poullis, C., You, S., 20091[1], Sun, S., Salvaggio, C., 2013[2]). In our previous paper we reconstructed a small-scale 3D campus model manually from LiDAR point clouds with an aid of AutoCAD civil 3D (Kawata, Y. et al., 2012[3]). In this study we extended it to an automatic reconstruction work for 3D city model from LiDAR point cloud data by applying a combination of several image-processing techniques. The softwares for reconstructing a 3D city model from the airborne LiDAR data were implemented by using IDL (Interactive Data Language) [4]. For a 3D representation of reconstructed 3D city, we utilized cgSurface command, which is a part of Coyote Graphics System[5].

AIRBORNE LiDAR DATA

In this study we selected Kanazawa railway station area, as a typical urban environment scene. The airborne LiDAR point cloud data used in this study is the data set of HC2533, a small subset of RAMS-E (Remote Airborne Mapping-Eartheon) data sets, which cover major cities in Japan. The coordinate system of HC2533 is based on Japan Geodetic Datum 2000 and Japan Plane Rectangular CS VII. The scene of Kanazawa railway station area is illustrated by the top view of airborne LiDAR data set of HC2533 in Figure 1.



ID	Z_1	Z_2	Color
0	1.5m	5.0m	
1	5.0m	10m	
2	10m	15m	
3	15m	20m	
4	20m	25m	
5	25m	30m	
6	30m	35m	
7	35m	40m	
8	40m	45m	
9	45m	50m	
10	50m	60m	
11	60m	70m	
12	70m	80m	
13	80m	90m	
14	90m	100m	
15	100m	110m	
16	110m	120m	
17	120m	130m	
18	130m	140m	
19	140m	144.5m	

Figure 1. Top view of the LiDAR data covering Kanazawa railway station area, which is color segmented by 20 altitude ranges. The size of the area roughly corresponds to 1.0 km x1.0 km and we have about 1.5 shots per every $4m^2$. The roof of railway tracks crosses Figure 1 in the slant direction.

BASIC APPROACH

In the proposed method, the LiDAR point cloud data is processed in four steps as follows:
(1) Preprocessing: Because of the LiDAR's random shots, we resample a raw LiDAR data into a new LiDAR data on a regular grid with equal grid span. Then, we make a gray scale LiDAR image, in which a gray level at the pixel location (X, Y) is assigned to the altitude Z, where (X, Y, Z) is a point cloud information of the resampled LiDAR data is utilized.
(2) Noise removal: We applied morphological operations, such as the opening and closing, to the gray scale LiDAR image for removing unnecessary noises.
(3) Extraction and extrusion of connected regions: The connected regions are extracted by looking at either 4 or 8 neighbors when searching for connectivity in an altitude mask image which is a binary image. Assuming certain threshold ranges of the altitude generates the altitude mask images. The altitude for each of connected regions was given by computing an average altitude over the corresponding pixel locations of the gray scale LiDAR image. The automatic extrusion of the connected regions is done using their assigned altitude.
(4) Integration process: The completion of 3D city landscape reconstruction is implemented by the integration of the connected regions, which are extracted and extruded automatically from all altitude mask images.

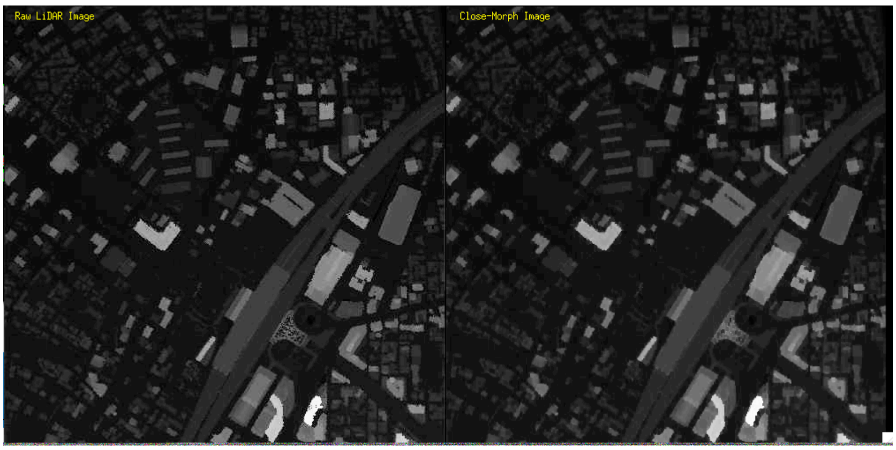
ANALYSIS AND RESULTS

The proposed method has been tested on the airborne LiDAR data covering over Kanazawa railway station area. The procedures for an automatic reconstruction for 3D city model are described here.
(1) Preprocessing: Since the laser shots were randomly shot into target area, the raw 3D LiDAR data point is not exactly on the regular grid of the target area. First of all, we resampled the raw 3D LiDAR data into that on a grid with equal grid span. As for the LiDAR point cloud data of Kanazawa railway station area, the raw LiDAR data is resampled on a regular grid with a grid span of 2.0 m, based on the nearest neighbor algorithm. Then, we make a gray scale LiDAR image, in which we assign the altitude Z to a gray level at the pixel location (X, Y), when we have a point set (X, Y, Z) of the resampled LiDAR data. In this study we generated a gray scale LiDAR image so that we have a image of 500 x 500 pixels and whose gray level Z is between 1 and 148, namely, $1 < Z < 148$.
(2) Morphological Operations for Noise Removal: To clarify the basic shapes and features within the gray scale LiDAR image, the morphological image processing operations are performed. In this study the morphological closing operation, which is dilation $\oplus$ followed by erosion Q, is applied to the gray scale LiDAR image.

The closing of gray scale Image ***GI*** by structure element ***SE*** is defined by Equation (1):

$$CloseIm = GI \bullet SE = (GI \oplus SE) \Theta SE \qquad (1)$$

Where we assumed ***SE*** = a rectangle structural element, consisting of 2 pixels in horizontal direction x 3 pixels in vertical direction. By the closing operation we can remove unnecessary noises from the image while maintaining the sizes of primary buildings and other objects within the image, as is shown in Fig.2.



(a) Gray scale LiDAR image (b) ***CloseIm*** after morphological opening

Figure 2. Gray scale LiDAR images over Kanazawa station area (brightness correction applied to the original LiDAR image for a better visualization purpose)

(3) Extraction and Extrusion of Connected Regions: Suppose that the gray scale image after the opening operation is denoted by ***CloseIm*** and we can generate an altitude mask image, Msk (i), using the following Equation (2).

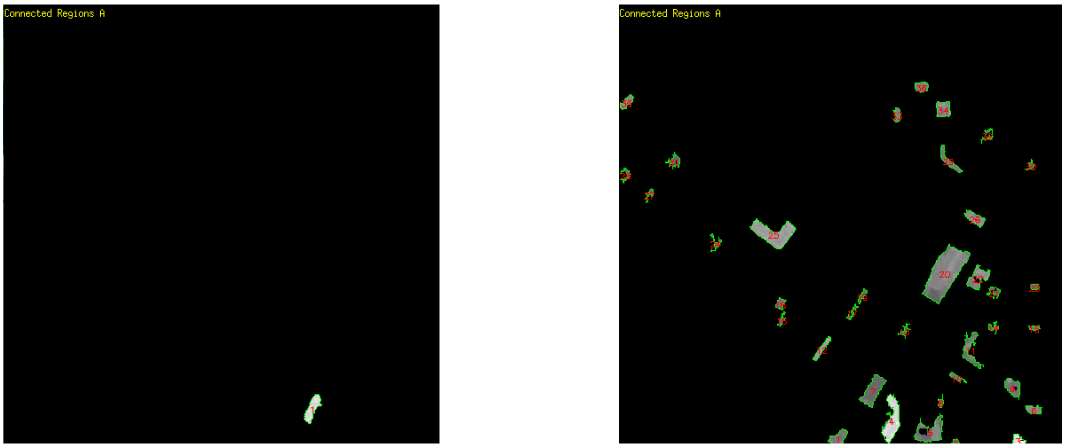
$$Msk(i) = \begin{cases} 1 & \ldots\ldots \quad H_{i+1} < Z < H_i \\ 0 & \ldots\ldots \quad Otherwise \end{cases} \tag{2}$$

where i = 0, 1, 2, ..., n, Z is the gray level of ***CloseIm*** and H_{i+1} and H_i are altitude thresholds.

In this study we generated 7 altitude mask images, Msk (0), Msk (1), Msk (6), assuming threshold values, namely, H_0= 255m, H_1=100m, H_2=40m, H_3=30m, H_4=30m, H_5=20m, H_6=15m H_7=10m, and H_8=1m. We should note that the altitude range is 1m < Z < 148m in the current scene of ***OpenIm***.
Definition of 7 binary images are explicitly given below:

Msk(0) ..... when 100m < Z < 255m
Msk(1) ..... When 40m < Z < 100m
Msk(2) ..... when 30m < Z < 40m
Msk(3) ..... when 20m < Z < 30m
Msk(4) ..... when 15m < Z < 20m
Msk(5) ..... when 10m < Z < 15m
Msk(6) ..... when 1m < Z < 10m

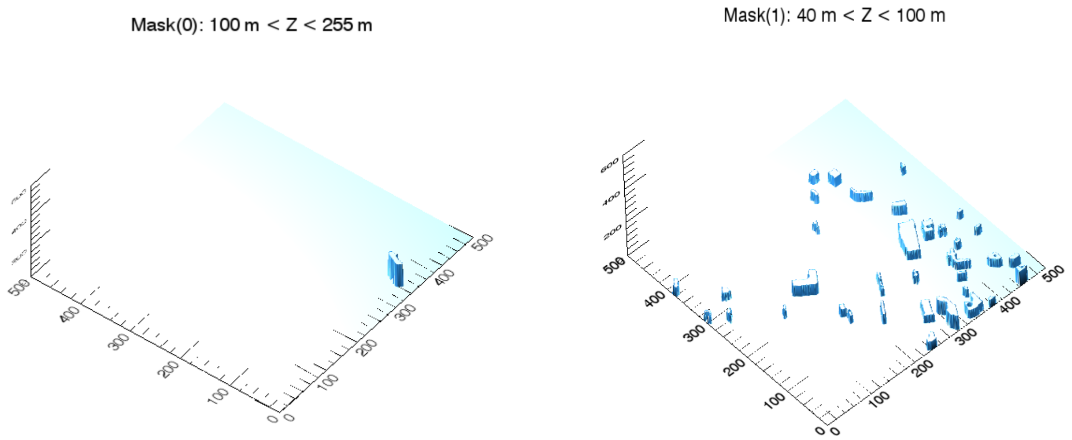
The labeling processing searches the connected regions in the altitude mask image and assign them a unique integer value. The detail algorithms for labeling process should be referred to [5]. In this processing the connected regions are searched by looking at 4 neighbors when searching for connectivity in the altitude mask image. The altitude assignment for each of connected regions is made by computing an average altitude over the corresponding pixel locations of ***CloseIm***. The result of labeling processing for Msk(0) when 100m < Z < 255m is shown in Figure 3 (a) and a single building outline with an average altitude of 137m is extracted from Msk(0). For next altitude mask image, Msk(1) when 40m < Z < 100m, the result is shown in Figure 3 (b) and many connected regions are generated in this case.



(a) Extracted region for Msk (0): 100m<Z<255m (b) Extracted regions for Msk (1): 40m<Z<100m

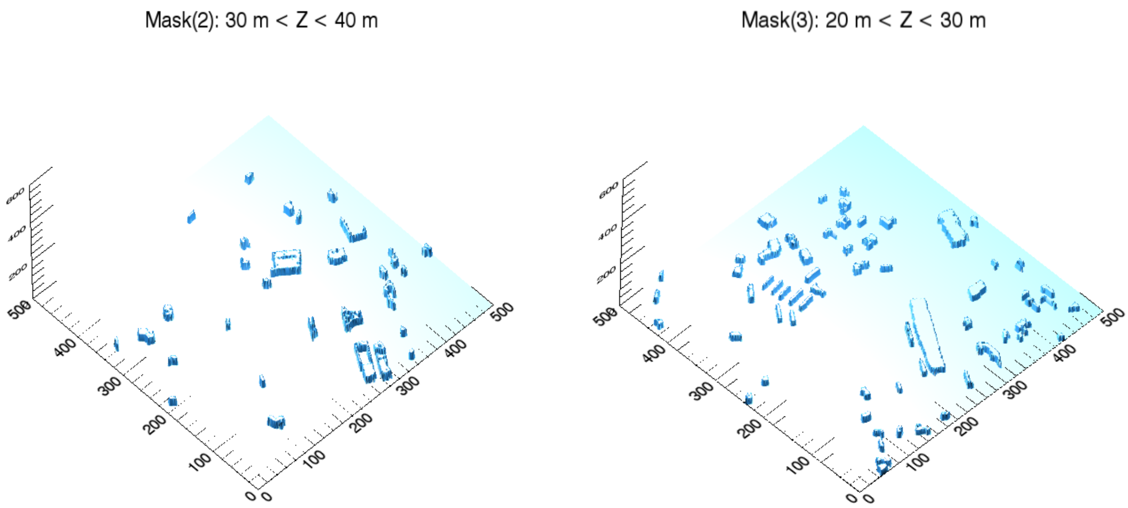
Figure 3. Connected regions by labeling process, using altitude mask images, Msk (0) and Msk (1).

The automatic extrusion of the regions is shown in the cases of Msk(0) and Msk(1) in Figure 4-(a) and -(b). The remaining automatic extrusions of the connected regions are shown in the cases of Msk(2), Msk(3), Msk(4), Msk(5), and Msk(6) in Figure 5-(a), -(b) and Figure 6-(a), -(b), and -(c), respectively.



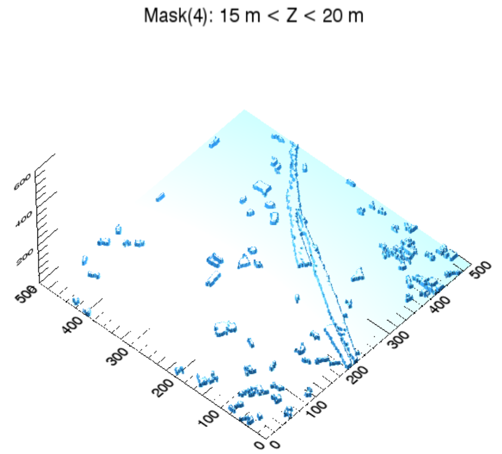
(a) From Msk(0): 100m<Z< 255m. (b) From Msk(1): 40m<Z< 100m.

Figure 4. Automatic extrusions of connected regions extracted from (a) Msk(0): 100m<Z< 255m and (b) Msk(1): 40m<Z< 100m. The amount of altitude extrusion for each connected regions is given by computing an average altitude over the corresponding region in ***CloseIm***. For 3D representation we utilized the cgSurface command, which is a part of Coyote Graphics System[5] in IDL programming. The tallest building is extruded in (a) and other tall buildings are extruded in (b).

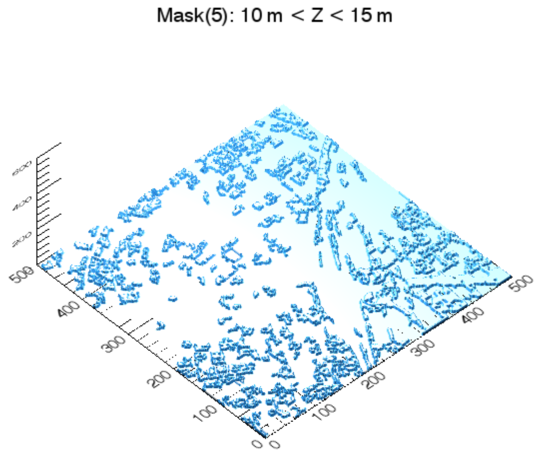


(a) From Msk(2): 30m<Z< 40m : (b) From Msk(3) : 20m<Z< 30m.

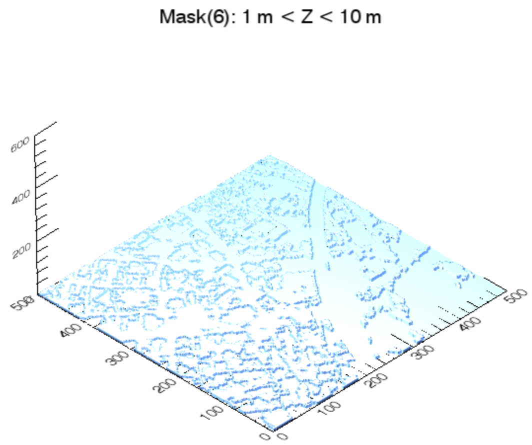
Figure 5. The same as in Figure 4, except from (a) Msk(2): 30m<Z< 40m and (b) Msk(3): 20m<Z< 30m. The main front and rear gates of Kanazawa station are extruded in (a). The roof of Kanazawa station, covering main railway tracks is extracted in (b).



(a) From Msk(4): 15m<Z< 20m



(b) From Msk(5): 10m<Z< 1520m,



(c) From Msk(6): 1m<Z< 10m

Figure 6. The same as in Figure 4, except from (a) Msk(4): 15m<Z< 20m, (b) Msk(5): 10m<Z< 15m and (c) Msk(6): 1m<Z< 10m. The roof structure, covering railway tracks is extracted in (a). Bus terminal platforms of the station square are extruded in (b). The miscellaneous background objects, small houses are extruded in (c).

(4) Integration of all connected regions

We can reconstruct automatically a 3D city model by combining all connected regions extracted and extruded from 7 altitude mask images (i.e., summing up all extruded objects in Figures 4, 5, and 6). The result of automatic reconstruction of 3D Kanazawa railway station area is shown in Figure 11.

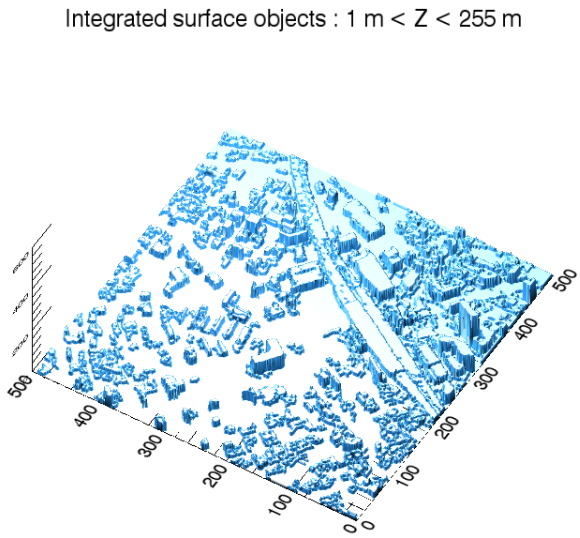


Figure 12. Automatic reconstructed 3D Kanazawa railway station area by integrating all of the connected regions extracted from the altitude mask images.

DISCUSSIONS AND CONCLUSIONS

In this study we have successfully demonstrated to reconstruct a 3D Kanazawa railway station area automatically by the integration of all connected regions extracted from 7 altitude mask images. These mask images are generated from the gray scale LiDAR image by the altitude ranges. We have some limitations in this study. Since airborne LiDAR point cloud data does not have information on the sides of buildings, the sides of reconstructed objects are connected to the ground by vertical walls, which is obviously lacking in reality. Furthermore, the treatment of the outlines of connected regions is not sufficient and an additional method for finding a rectilinear boundary of a region should be included in our proposed method, since most buildings have rectilinear outlines. The accuracy of 3D city landscape reconstruction by this approach depends on the number of altitude mask images and the minimum pixel points (MinPt), constituting a connected region. In this study, we assume 7 altitude mask images, namely, Msk(0) ~ Mask(6) and MinPt = 50. We confirmed that we had a more detailed building shapes with more computer time when MinPt =10 was adopted.

We can conclude this study as follows:

1) We proposed a simple reconstruction method for 3D urban landscape automatically from airborne LiDAR point cloud data, by using a combination of image processing techniques.

2) The automatic reconstruction of a 3D Kanazawa railway station area was successfully demonstrated by applying a proposed method.

3) Further experiments on increasing the number of altitude threshold range and the minimum number of pixels constituting a connected region are certainly needed for improving the proposed method.

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