THREE-DIMENSIONAL CITY MODELING FROM AIRBORNE LASER SCANNING

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ABSTRACT

A method to automatically make 3-D city models from airborne laser scanner data was developed. By comparing another 3-D model made using 2-D map data, the 3-D data specifications are discussed from a cartographic aspect. Though there are normally no boundary data between parts of a building with different stories in 2-D map data, we consider the distinction is necessary for 3-D modeling. This indicates a merit of segmentation method of laser scanner data in 3-D modeling.

Keywords: 3-D, virtual reality, multimedia, city model, buildings, laser scanner, lidar, DTM, DEM, DSM, GIS, data acquisition

1. INTRODUCTION

Three dimensional city models are attracting much more attention than ever due to the potential of its applications to many fields such as city planning and disaster mitigation planning by helping the planners through providing them with realistic scenery, and radio wave propagation analysis for mobile phone antenna location analysis. This is based on computer technology development and increasing availability of 3-D GIS environment and/or 3-D visualization tools on computers. As the objects expressed in the models are ground features, topography, and so forth, the expression of these models should also be discussed in a viewpoint of cartography.

It is necessary to create 3-D city model data at first. Airborne laser scanner (It is sometimes called lidar.) is one of the most promising tools that measure 3-D shapes of terrain and ground objects. It directly provides the x, *y* and *z* coordinates of points densely distributed on the surface of ground objects, or *z* values at dense regular grid interval. These data are not suited for GIS applications in their original form because the data amount is huge and ground objects are not distinguished in these raster type data. Therefore it is necessary to reconstruct appropriate geometric models representing buildings, houses and other ground features in vector format from these data.

We have developed a method for 3-D city model generation from high-density elevation data obtained by a laser scanner borne on a helicopter. This paper describes the outline of the method together with introductory explanations of airborne laser scanners, the results obtained by the method, another type building models for comparison and discussion of issues raised in expressing 3-D city models.

2. AIRBORNE LASER SCANNER

An airborne laser scanner (ALS) is an active sensor that measures the distance from the sensor to the target on which the laser beam is reflected. By a scanning mirror mounted in front of laser transmitter/receiver measures it many points in cross-track direction and area with some swath width is measured along with the forward movement of the aircraft. Sensor positions and attitudes as well as scanning angles of the mirror are measured onboard. The three-dimensional positions of the ground targets are obtained by combining these data with measured distances from the sensor (Fig. 1)

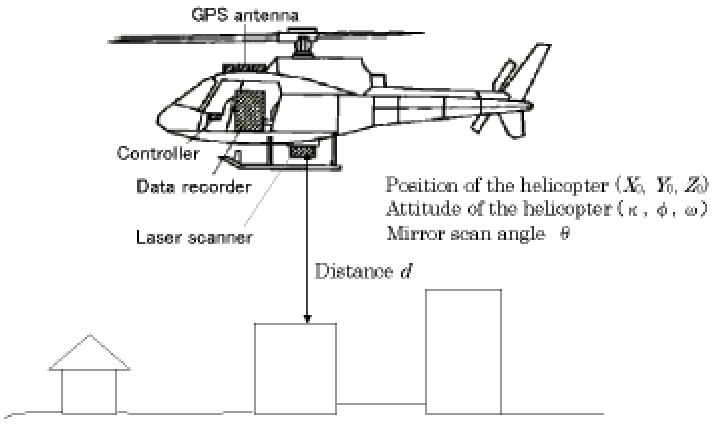

Figure 1 Measuring principle of the ALS

The data obtained at first is a collection of the x, *y* and *z* coordinates of points randomly distributed in space (point cloud). These data can be used to make surface data of the ground and ground features. But it is often more convenient to use height data at regular grid intervals. These grid DEM type data are made by interpolation of the original data. Both type data express the surface of the ground as well as ground features such as buildings and trees. Therefore they are called digital surface model (DSM) to distinguish them from DTM that means the ground height data without buildings and trees.

The advantage of airborne laser scanning is the capability to obtain detailed DSM in digital form very promptly compared with digital photogrammetry. It has also the capability to measure the ground under vegetation cover when trees are not dense. The height measuring accuracy is as high as 10-30 cm but horizontal accuracy is worse than height accuracy and is about one meter (Masaharu et al., 2001). For more details about airborne laser scanning, please refer to Ackermann (1999), Wehr and Lohr (1999) and other articles in the same issue of the ISPRS Journal of Photogrammetry and Remote Sensing.

3. THREE-DIMENSIONAL CITY MODELING WITH REGION SEGMENTATION

Many researchers have studied on the methods of making 3-D city models using airborne laser scanner data (Haala and Brenner, 1999; Stilla and Jurkiewicz, 1999; Maas and Vosselman, 1999). They have developed methods to reconstruct roof shapes from laser scanner data together with 2-D map data that give building shapes projected on the ground. We have developed a method that uses only laser scanner data for extracting buildings and trees and make 3-D models from these boundary data (Masaharu and Hasegawa, 1999; Masaharu et al., 1999; Masaharu and Hasegawa, 2000). Our method can provide fairly good 3-D views from automatic processing of laser scanner data although some building shapes are distorted reflecting the measuring accuracy of the original data and omission can occur in some cases. The latter problem can be solved by combining building area extraction method using normalized DSM (Masaharu et al., 2000; Masaharu et al., 2001).

3.1 Outline of region segmentation method for building extraction

We used grid DEM type data obtained by a heliborne laser scanner and interpolated into 0.5 m grid intervals. At first, boundary polygon data of buildings are obtained from region segmentation of the elevation data. Basic idea of the method is as follows. Each building has a distinct height difference from the surroundings. Therefore we can distinguish each building by segmenting the DSM with the condition that a pixel having the height difference within a predetermined threshold from a neighboring pixel belongs to the same region. Boundary data of building polygons are obtained from the segmented image. By combining the polygon data obtained by this method with the original DSM, 3-D city model is generated.

3.2 Region segmentation

The height differences between neighboring grid points are checked with a predetermined threshold value. If the difference is within the threshold, then the grid point belongs to the same region as the neighboring grid point and they are assigned the same label number. Four-neighbor relationship is used to judge connectivity. The DSM grid data are converted to a segmented image with label numbers as its pixel values through this process. Detailed description of the algorithm is written in Masaharu et al. (1999).

3.3 Boundary tracking and 3-D model generation

Labeled image is created as the result of region segmentation. Then boundary tracking of each segmented region is carried out. Because the resulting coordinate data of vertices of the boundaries are much redundant, unnecessary vertices were eliminated using Douglas-Peucker algorithm (Douglas and Peucker, 1973). Regions with distinctive height difference with their surroundings are extracted in the form of polygon data in this process.

Next step is to combine these polygons with the height data of the laser scanner. A 3-D city model was generated by assigning median height in each region obtained from laser scanner data to the polygon data.

3.4 Distinguishing buildings and trees by statistical method

The city model includes both buildings and trees. These should be distinguished and expressed in a different manner. We used statistical classification method for this. Tree regions are expected to have large dispersion of heights compared to building roofs. Therefore we used standard deviation of height values within a region divided by the area of the region. By applying discriminant analysis method to this one variable, we obtained 94% correct answers for supervisor data. Correct answers for buildings were 79% and those for trees were 99% (Ohtsubo et al., 2000; Masaharu et al. 2001). Although we found the classification thresholds were different in different test sites, this method has the advantage that it can be applied when only DSM data is available.

3.5 Result of the region segmentation method

3-D city models of Minokamo city and Tsukuba city made by the method are shown as bird's-eye view in Figures 2 to 4. Trees are shown in different tint from buildings. Ground surface is also expressed with layer tints. The results show that complicated shape buildings that have parts with different stories as well as those having some objects such as cooling towers and water tanks on the roofs are well modeled. This shows 3-D modeling capability of the laser scanner data.

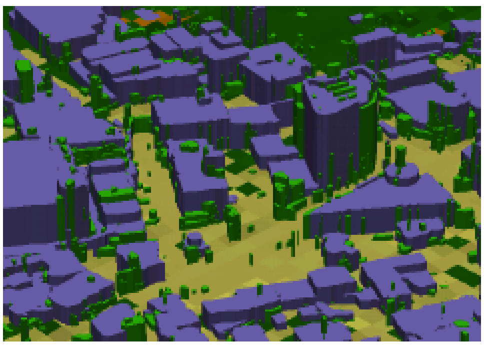

Figure 2 Three-D model of Minokamo city

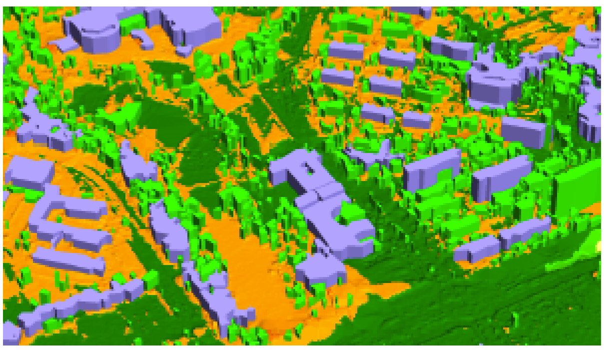

Figure 3 Three-D model of Tsukuba city (1)

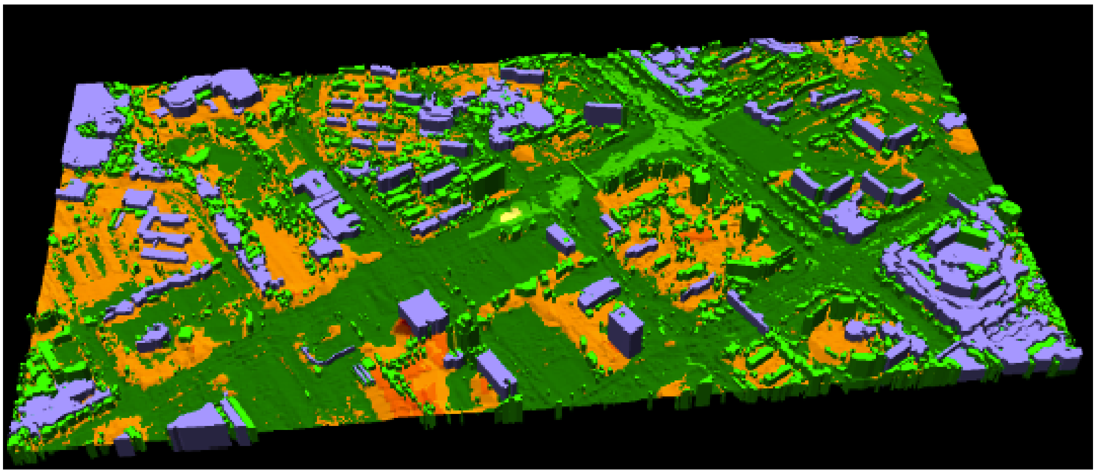

Figure 4 Three-D model of Tsukuba city (2)

4. THREE-DIMENSIONAL CITY MODEL USING 2-D MAP DATA AND HEIGHT DATA FROM LASER SCANNER

We now show another approach for 3-D modeling. Ordinary two-dimensional vector map data of buildings were used as boundary polygons of buildings and height of each building was taken from laser scanner data. Representative height value was measured interactively for each building (Hayata et al., 1999). Two scenes from 3-D model of Tsukuba city are shown as Fig. 5 and 6. Road networks are also shown in thin lines.

By comparing Fig. 2-4 with Fig. 5 & 6, the former model has more information such as trees and detailed shape of buildings. Objects such as cooling towers on roofs (ex. an advertisement tower on the triangle-shaped building in Fig. 2) and buildings having different stories with themselves are well modeled. On the contrary, the latter looks less noisy. But all the building is given only one height for its entire region. This makes the shapes of buildings unrealistic for some large buildings that have different stories in the same building boundary polygon. Ordinary 2-D map data do not provide information on parts of buildings with different height. If we want to overcome this problem, then we need again to segment regions using laser scanner data. This indicates a merit of segmentation method of laser scanner data in 3-D modeling.

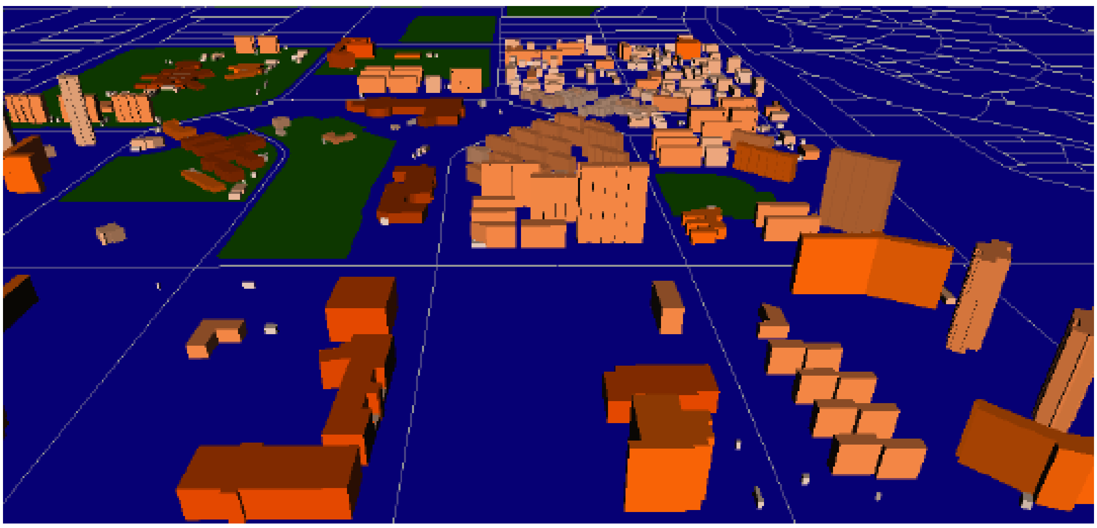

Figure 5 Three-D model of Tsukuba city using 2-D map data and laser height

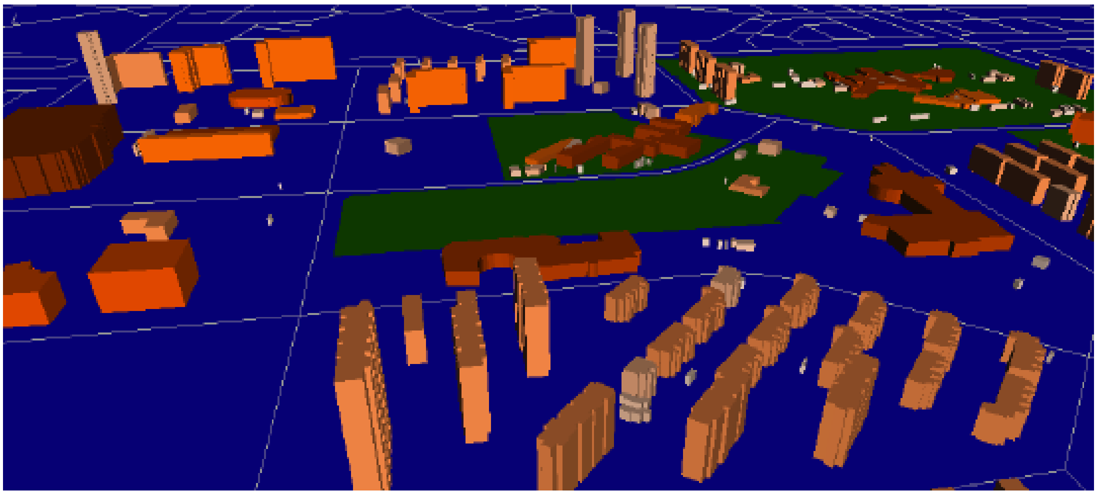

Figure 6 The same 3-D model of Tsukuba city from another angle

5. DISCUSSION

Our experience of 3-D city modeling raised some issues to be discussed in view of cartography. The major issue is cartographic abstraction or generalization in 3-D models. Representation of geographic information on 2-D plane has been the subject of traditional cartography. Many techniques have been developed for efficient communication of geographic information. But it is not clear whether these are applicable to 3-D models in the same way. Although researchers have already tackled 3-D modeling and its use in cartographic point of view (Cartwright et al. eds., 1999), we consider there remain issues to be solved. These can be summarized as follows.

- System for representing 3-D space
- 3-D data acquisition
- Level of detail in 3-D data; generalization
- Application of 3-D models

As for 3-D representation software, we used ArcView with 3D Analyst extension, ERDAS Virtual GIS and web browser with VRML plug-in. The region segmentation program was written by ourselves but we utilized these 3-D GIS environments extensively for both processing the data and viewing the 3-D data. The 3-D GIS software has the functionality to export 3-D data in VRML format. This allows circulation of the 3-D data among users. Therefore it can be said that there are not urgent problems for viewer software of 3-D model for the time being.

Data acquisition is important because the legacy data of maps contain only two-dimensional information except for ground elevation expressed by contour lines and spot heights. Airborne laser scanners, as we already discussed, provide very detailed height information and it is a promising tool for 3-D data acquisition. Our effort is devoted to utilize these data for 3-D model generation. Other approaches have also their own advantages. Aerial photographs give higher resolution than laser scanners. Shi (1997) developed a method to automatically extract buildings from stereo aerial photos and Gruen and Wang (1998) developed a system to automatically generate 3-D topology for building models with manually taken point data from a stereo-plotter. One problem concerning data acquisition is that objects under overpasses and elevated railroads cannot be measured with aerial sensor data. Other approaches are necessary to obtain real 3-D data of these urban structures.

The level of detail of 3-D data, in other words degree of cartographic generalization for 3-D, has not been touched fully. From our experience, we judge in the following way.

1. Buildings having parts of different stories should be expressed as they are.
2. Large objects on the roofs should be expressed.
3. Small unevenness of building shape should be omitted, by and large according to scale, as is the same as 2-D maps.

As for the 1st and 2nd statement, we have already discussed in Section 4. More clarification may be necessary for the 3 rd statement. The 3-D viewer gives the user freedom of movement of viewpoint. This means that arbitrary objects in the 3-D space can be seen from very near position. But it is impossible to prepare every detail in the data. Therefore the 3-D data needs to be specified with the maximum scale to be viewed properly. When the objects are viewed from a distance, the viewer software can automatically calculate appropriate level of detail to represent the objects.

Another aspects relating to 3-D data is the application of the data. Data preparation is closely related to its application. For example, a 3-D model made by region segmentation method consists of independent prismatic shapes. It is enough for reconstructing scenery but it will be necessary to identify each building composed of many prisms as one object in GIS applications. Furthermore, cost of data preparation and the benefit expected to get from the data should be considered. In this regard, specifications of basic or fundamental 3-D data should be established in order to avoid duplicated data preparation.

6. CONCLUSION

Methods for making 3-D city models from airborne laser scanner data have been developed. The usefulness of laser scanner data for this application was confirmed. The nature and specifications of 3-D geographic data need further research from cartographic viewpoint.

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