THREE-DIMENSIONAL CITY MODELING FROM LASER SCANNER DATA BY EXTRACTING BUILDING POLYGONS USING REGION SEGMENTATION METHOD

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ABSTRACT

We have developed a method to automatically generate a 3-D city model only from laser scanner data by applying region segmentation to the grid type data of digital surface model (DSM) obtained by the scanner. Each building has a distinct height difference from the surroundings. Therefore we can distinguish each buildings 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.

Results are given for parts of two different type cities, Minokamo and Tsukuba, Japan. We evaluate from these results that this method is useful to promptly obtain 3-D city models in vector format because the model is generated through automatic processing of the data. But the resulting model is not yet suited for direct usage in GIS because the resulting polyhedrons obtained by this method correspond to parts of buildings and not necessarily to each building. It is suited in particular for 3-D scenery reconstruction as can be seen in the figures of the bird's-eye view.

This method, however, has its intrinsic problems that in some condition even large buildings cannot be distinguished from road surface. This means that these buildings disappear in the obtained 3-D model. Another problem is that the extracted objects are not always buildings or houses but, for example, trees are included. These issues are also discussed in the paper.

1 INTRODUCTION

Three dimensional city models handled in a 3-D GIS environment are attracting much more attention due to the potential of its applications to many fields and increasing availability of 3-D GIS environment. For that purpose, it is necessary to create 3-D city model data. Airborne laser scanner is one of the most promising tools that measure three-dimensional shapes of ground objects. But it provides in principle only the x, y and z coordinates of points densely distributed on the surface of ground objects, or z values at dense regular grid interval (grid DEM type data). Therefore it is necessary to reconstruct appropriate geometric models representing buildings, houses and other ground features from these data.

A number of researches have been carried out to make detailed 3-D building models by using both 2-D digital map data and laser scanner data (Haala and Brenner, 1999; Maas and Vosselman, 1999; Stilla and Jurkiewicz, 1999). As 2-D digital map data in vector format are available in many cities nowadays, this method would be useful and applicable. But changes taking place between digital map data provision and laser scanner data acquisition are problem in this method.

We started to develop methods in which only the laser scanner data are used for reconstructing 3-D city model so that we can explore the possibility of this sensor in obtaining three-dimensional spatial data. One of the merits of the laser scanner sensor is that it can provide digital data within a few hours after the flight. This swiftness will be useful for many applications. In this regard, we consider this approach is advantageous because no other data than laser scanner data are necessary and the processing will be done automatically in principle.

We have developed a 3-D city model generation method based on region segmentation of laser scanner data. The results are presented and the problems of the method and future study items are discussed.

2 METHOD

The method is extracting buildings from high-density elevation data obtained by a laser scanner carried on a helicopter by applying region segmentation method to the elevation data. Basic idea is as follows. Each building has a distinct height difference from the surroundings. Therefore we can distinguish each building by segmenting the DSM (digital surface model) 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, three-dimensional scenery of urban area is generated. Outline of the method is given here and more detailed explanation of the method is written in Masaharu et al.(1999).

2.1 Region Segmentation

The region segmentation is carried out as follows. The height differences between neighboring grid points are checked against 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 laser scanner data used here are given as elevation data at grid points with 0.5 m regular grid interval representatively.

Before applying the region segmentation, 3 x 3 median filter was applied in order to eliminate isolated point noise in the original data.

2.2 Boundary Tracking

Labeled image that has label numbers of segmented regions as pixel values 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). In this way, regions with distinctive height difference with their surroundings are extracted in the form of polygon data.

2.3 3-D Model Generation

Next step is to combine these polygons with the height data of the laser scanner. A 3-D city model was generated by applying a program originally made for generating 3-D city models from building polygons of a digital map and laser scanner DSM (Kamiya and Hasegawa, 1999), to the polygon data obtained from laser scanner data.

3 RESULTS

3.1 Laser Scanner Sensor Used in the Study

The data were taken by a heliborne laser scanner system. The pulse frequency is 20000 pulses/s and the scanning frequency is 25 lines/s. The scanning width is 60°. These figures give the ground resolution of about 0.5 m in both cross track and along track direction when the helicopter flies 250m above the ground at a speed of 50 km/s. The beam width is 2.5 mrad which corresponds to also about 0.5 m spot size on the ground. For more detail about the specifications of the sensor system, please refer to Masaharu et al.(1999).

CCD linear array color optical sensor is attached near the laser scanner. Thus we can get optical images simultaneously and digital ortho image can be created (Hasegawa et al. 1998; Murakami et al., 1999)). Although this feature of the sensor system was not used in the 3-D model construction written here, possible applications of this feature are discussed.

3.2 An Example of Minokamo City

Minokamo city is an intermediate scale city with about 46,000 population in Gifu prefecture, central Japan. The central area of the city was selected as the test site. There are densely gathered traditional houses and rather small number of middle to high-rise buildings.
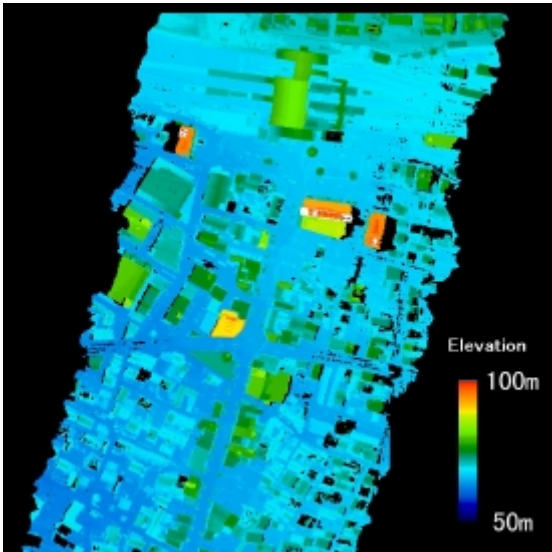
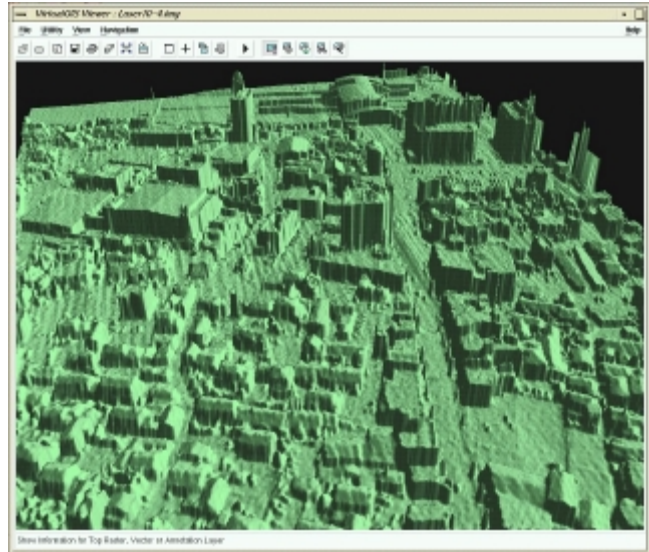Figure 1. Laser Scanner Data of Minokamo City (A Portion)

Figure 2. Bird's-eye View Representation of Laser Scanner Data

The data were taken in February, 1998 and shown as Figure 1 in layer tint image.   The data used here is the height data in regular grid spacing of 0.5 m produced by the software of the sensor system. Bird's-eye view of this original data is shown in Figure 2.   An area were cut from the original data for testing the method.   The size of the area is 400 x 800 pixels, which corresponds to 200m x 400m.   The threshold of region segmentation was determined as 0.4 m after try and error.   Figure 3 shows the obtained polygon data after generalization. 3-D model is obtained by determining heights and roof shapes of buildings using the laser scanner data and the polygon data.   Figure 4 shows the obtained 3-D model as bird's-eye view.

3.3   An Example of Tsukuba City

Tsukuba city was newly developed around 1980 according to the government policy to concentrate national research institutes.   The population is about 160,000.   Many of the buildings in the city central area are high-rise buildings with 4 to 13 stories and detached houses are few.   As the size of each building is large, one-meter resolution height data, which was made by averaging 2 x 2 pixels of the original data, was used in the processing.   The size of the area is 1200 x 600 pixels and is 1200m x 600m.   The threshold for region segmentation was 0.8 m. Obtained polygon data is shown in Figure 5 and the bird's-eye view of the 3-D model is shown in Figure 6.

4   DISCUSSION

4.1   Evaluation of the Results

The polygons extracted by region segmentation (Figure 3 and Figure 5) are rather complicated and somewhat distorted.   Actual shapes of buildings and houses are very complicated when objects on the roofs are

Figure 3. Extracted Polygons by Region Segmentation, Minokamo City

taken into account.   Furthermore many buildings have parts with different stories.   There are also many trees along the street in both cities.   The complicated structure reflects these circumstances.   We consider the distortions of the resulting polygon shapes are mainly due to the position and attitude measuring error of the sensor system.   We expect that more accurate shapes can be derived from laser scanner data in the near future by improved sensor systems.

The 3-D model obtained by assigning heights to each polygon, nevertheless, looks rather realistic. The complexity is mitigated by adding one more dimension. On the other hand, this method separates the parts having different stories of a building and also separates objects on roofs. This makes the 3-D scenery realistic.

In this regard, this method has advantage over the method that uses existing map data for planimetric shape and gives homogeneous height to it from laser scanner data. By comparing these two methods, the followings were found. First,
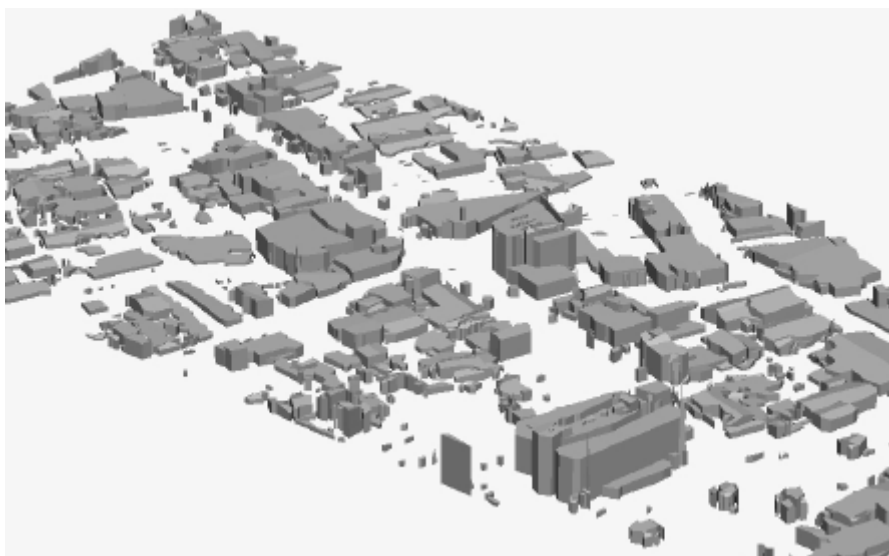

Figure 4. Bird's-eye View of the 3-D Model, Minokamo City
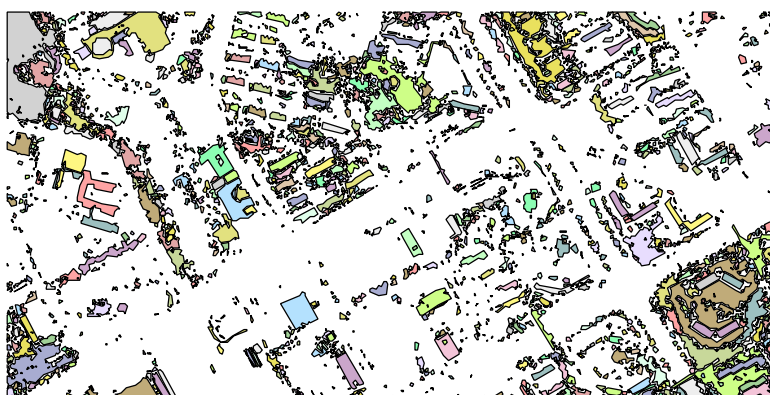

Figure 5. Extracted Polygons, Tsukuba City

Figure 6. Bird's-eye View of the 3-D Model, Tsukuba City

it is not necessary to consider horizontal displacement between polygon data and height data in region segmentation because the source data is the same. On the other hand, it is necessary to consider the displacement when using 2-D map data because there are positioning errors in laser scanner system. Second, region segmentation method has no such problem of changes caused by time difference between the polygon data and height data.

We have tried another method to derive building boundaries using edge detection technique (Hasegawa et al., 1999). In this method, it is rather difficult to obtain closed polylines to compose polygons. On the contrary, region segmentation method gives closed polylines in very natural way.

The region segmentation method, however, has its intrinsic problems that in some condition even large buildings cannot be distinguished from road surface. This is related to the selection of the threshold of region segmentation. Another problem is that the extracted objects are not always buildings or houses but, for example, trees are included. The separation of buildings and trees is a problem to be solved. These problems are discussed in the following sections.

To summarize, except for the above mentioned problems, the region segmentation of laser scanner data is a good method to generate 3-D scenery model in the sense that the method can generate it through automatic processing and therefore makes the most of the merit of prompt data acquisition of laser scanner.

4.2 Appropriate Threshold Value for Region Segmentation

We thought at first the threshold would be around 1.5 m since the height difference between road surface and buildings seemed to exceed this value in any case. But many buildings were not extracted as different regions with this threshold. Figure 7 shows the extracted polygons with the threshold of 1 m and 0.5 m overlaid on the DSM image of the laser scanner data. It can be seen that many buildings are not extracted with the threshold of 1 m. It is seen that a large building (This is a supermarket actually.) at the lower end of the figure is not extracted even with the threshold of 0.5 m.

We consider the reason as follows. Individual regions derived from region segmentation have height difference with neighboring regions larger than the threshold at the entire boundary points. This means that two regions are merged into one region if there is a path where the height differences of adjacent pixels are under the threshold and thus connecting the regions. This is demonstrated at the above mentioned large building at the lower end of Figure 7. There is a slope leading to the parking on the roof of the building. This path connected the region of the roof of the building with the ground surface.

We found from field examination that failure to extract buildings happens where buildings have special shapes having slopes or staircases outside such as mentioned before, or where there are trees, such as garden trees, next to houses.

We estimate that appropriate threshold is about 0.5 m for the data with grid interval of 0.5 m from our experience. But some buildings are not extracted with this threshold. Reducing the
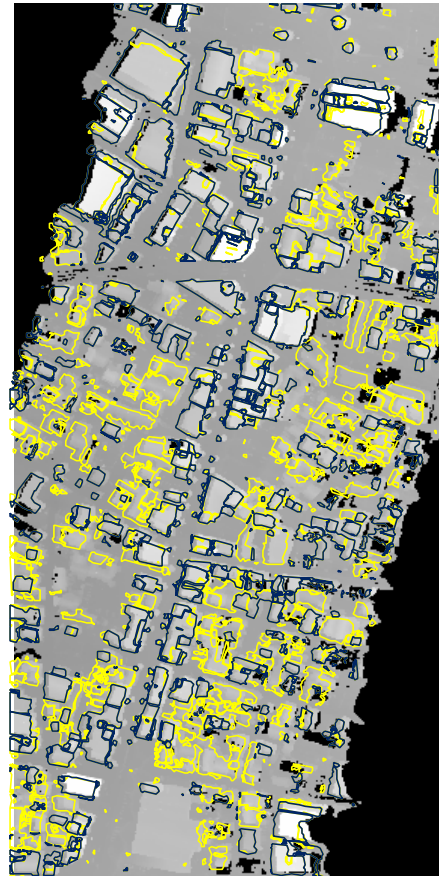
Figure 7. Extracted Polygons Overlaid on the Laser Scanner DSM
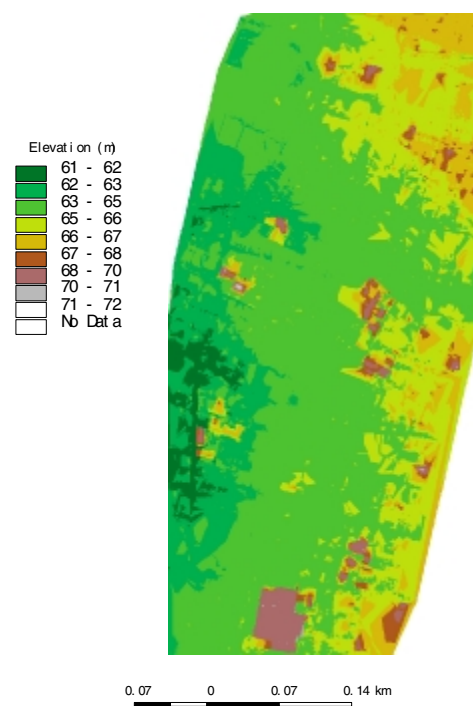(Threshold: Dark blue=1m, Yellow=0.5m)

Figure 8. Ground Surface DEM by Laser Scanner

threshold will increase the number of small regions and is not suited for modeling purposes. Therefore it is necessary to develop a method to cope with this omission. We plan to try developing combination of other techniques such as edge detection or contour lines of horizontal section.

4.3 Obtaining Ground Surface DEM

From the result of region segmentation, ground surface region is obtained as a complementary set of building regions. Then it is possible to derive ground surface DEM from laser scanner data by interpolating the regions of buildings from neighbor pixels on ground surface region using TIN (triangular irregular network) and averaging. This result is shown as Figure 8.

This is another application of laser scanner data and region segmentation. But in order to get correct ground surface, all the buildings have to be extracted. It can be seen that Figure 8 is not the case. Some buildings were not extracted and are shown to be unusual rise of the ground surface. This can be used, on the other hand, to detect the omission of building extraction.

4.4 Distinguishing Trees from Buildings

The region segmentation method cannot distinguish trees from buildings. To include trees in the 3-D model may not be bad for scenery reproduction but it is necessary to distinguish trees from buildings to have meaningful 3-D city model. We have not yet got results on this. We plan to use optical CCD sensor data obtained simultaneously. A new laser sensor can measure also the backscatter signal intensity. These data will be able to be used together for classifying trees and buildings.

5 FUTURE STUDY

As written in the previous section, the region segmentation method is still incomplete as a method to extract buildings from laser scanner data. One of the most important study items is to develop a method to prevent omission in building extraction. Another important study item is to distinguish trees from buildings.

We have used grid type data derived from laser scanner data up to now. Using original data expressed as a set of three-dimensional coordinates of reflection points should be explored.

We have described a method to make a 3-D city model only from laser scanner data in this paper. But it is necessary to combine various data sources in order to utilize the 3-D model in GIS environment. In this regard, it should be pursued to develop matching techniques of the laser scanner data with other data such as 2-D map data. There are problems of horizontal displacement of the scanner data due to measuring errors and changes of buildings due to time difference. To develop methods to cope with these problems is an important issue in order to expand the usefulness of the laser scanner data.

6 CONCLUSION

A method to extract boundary polygon data of buildings from laser scanner data was developed. The merit of this region segmentation method compared to other methods is that polygon data can be obtained in a natural way. By using the resulting polygon data, 3-D city model was generated. It demonstrates 3-D modeling capability of the laser scanner data. Although there still remains problems to be solved, this shows high potential of the laser scanner data and of this method for the 3-D data capture of urban area.

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