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3D City Modeling with Laser Range Data and 2D Maps

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Abstract

Visualizations and simulations in an urban environment need 3D digital maps rather than traditional 2D maps, and constructing 3D maps from multiple data sources has become a promising and challenging research area nowadays. In this paper, we propose a method for modeling roads, buildings, and ground from 2D digital maps and Laser Range Finder(LRF) data. Firstly, road surfaces are created through extracting road region on the input 2D map and elevating their vertexes by using LRF points inside the road region. Secondly, building's boundaries in the 2D map are modeled to cubes whose base and roof elevations are calculated from near LRF points. The ground is represented by Triangular Irregular Network(TIN)-based surfaces created from road boundaries, building's base boundaries, and flat area in LRF data. Some experiments are also carried out to illustrate the effectiveness of the proposed method.

1 Instructions

GIS(Geographic Information Systems) is capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their spatial information. Due to the shortages of 2D map based GIS systems and the fast progress in computer graphics, 3D map based GIS systems are strongly expected. As a result, constructing 3D maps from various data has become a promising and challenging research area nowadays. But, most of existing systems and technologies, which are used to create 3D maps, have traditionally been focussing on single or independent dataset. And, there are conflicts between efficiency and precision in most of existing methods. For example, traditional photogrammetry has worse efficiency because of its labor-intensiveness, and digital photogrammetry is limited by its poor precision. Some researchers added floor number to existing 2D maps to create pseudo 3D maps, which have not enough precision in elevation and lacking ground surface.

With the introduction of eye-safe laser, a Laser Range Finder (LRF) mounted on an aircraft can be used to gather 3D data, named as LRF data, of all ground objects. Theoretically, LRF data can be used to model all objects. However, it is necessary to gather LRF data of higher density to correctly model ground objects.

In fact, we have various 2D maps and much more data are becoming to be available continuously. It is efficient and economical to utilize the existing data to create new types of data or to construct new systems. Some researchers have tried to calculate the heights of buildings by matching a 2D map with LRF data. It is a promising effort. Not only buildings, but more objects such as roads and ground, are expected to be modeled from mutliple datasets.

In this paper, we propose a method for modeling roads, buildings, and ground by merging 2D digital maps with LRF data. In roads modeling, road edges represented by polylines in the 2D map are processed to create road region and consequently elevated to create a Triangular Irregular Network (TIN)[3] based road model. In buildings modeling, a cuboid model is used, where the base and roof elevations of the buildings are calculated from the near LRF points. A TIN-based ground model is obtained by creating TIN from the road model, the building's base boundaries, and flat space constructed by LRF data. Some experiments are also carried out to illustrate the effectiveness of the proposed method.

2 3D City Modeling Algorithms

2.1 Outline

The flowchart is shown in Figure 1. Both a 2D map and a LRF dataset are handled as inputs. The 2D map includes road edges, borders of buildings, and other information. The LRF data is a set of 3D points, where x and y values represent their positions and z values the heights, in the same coordinate system with the 2D map.

In our approach, the roads, buildings, and ground surface are modeled as described in the following sections.

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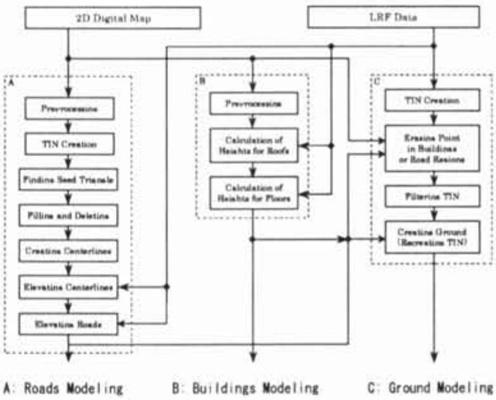

Figure 1: Flow Chart

2.2 Road Modeling

Generally, we can calculate the heights for all nodes on the road edges by finding the nearest point or near points from LRF dataset. This leads to that every road is represented by a pair of 3D polylines, which is unadvisable for 3D visualizations or simulations. It is desirable that roads are represented by 3D surfaces rather than polylines in a 3D map. In this paper, all road edges are grouped by creating and analyzing TIN, and elevated to create TIN-based 3D road models later, as shown in Figure 2 and described in the following steps.

2.2.1 Finding Road Region

Pre-processing includes *connecting*, *deleting*, and *resampling*. Road edges may be disconnected because digital maps are generally clipped to several blocks for convenience of storage. *Connecting* process is introduced to connect the clipped edges (Step A in Figure 2). There are also some isolated short edges or points in the layer of road edges. These short edges and points are deleted through *deleting* process beforehand (Step A in Figure 2). *Resampling* process adds and deletes nodes on every road edge to let the intervals between adjoining nodes be almost equal and while keeping the road's shape (Step B in Figure 2).

TIN Creation creates TIN from nodes of road edges with road edge segments as constraints (Step C in Figure 2).

Finding Seed Triangle is selected from the result of TIN Creation and possesses the following characteristics: (a) is an original triangle which has not been filled as road region; (b) has one and only one road edge, named *key edge*; (c) with the opposite point of the key edge, named *key node*, belonging to another straight road edge; (d) with the height, the distance from key node to key edge, being within the width range of real world roads; (e) has an adjcent triangle, which shares the same key edge and is not filled, named *co-triangle*; (f) has two acute angles except the key node; and (g) with the ratio between the height of the co-triangle and that of itself, named *possibility*, being more than 1 and the highest among all triangles of the TIN.

Filling and Deleting: *Filling* is the process of marking triangles as being within the road region from seed triangle recursively. In the filling process, any triangle around the current one is filled if the edge between the triangle and the current triangle is neither a road edge nor an end edge connecting two end points of road edges, and will be set to be the new current triangle after the filling is finished and the old current triangle is pushed to a current triangle's buffer. Filling process will be finished after all adjoining triangles around every current triangle are checked and filled if it should be. A road model is made of the filled triangles after *deleting* the unfilled triangles.

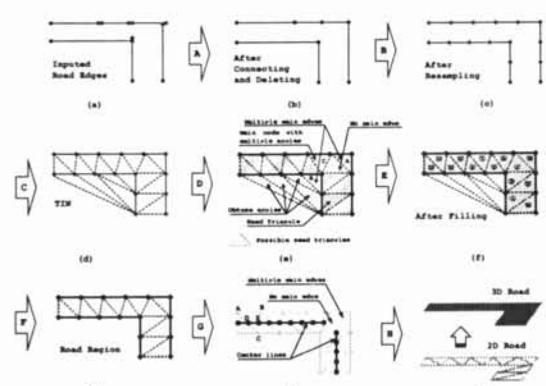

Figure 2: Road Modeling

2.2.2 Elevating Roads

Creating Center Lines: For every triangle which is filled as road region before and not located at a intersection, there are one road edge and two inner edges which are inside the road region. In triangle ABC shown in Figure 2(h), edge AB is a road edge and edges AC and BC are inner edges. Points D and E are midpoints of edges AC and BC respectively. Connecting two midpoints D and E creates a short segment DE, called centerline segment which is parallel to the road edge AB. *Center Lines* are created by connecting all adjoning centerline segments like DE.

Elevating Center Lines: The heights of the centerline's nodes are inherited from the nearest LRF point firstly, and smoothed by linear interpolation.

Elevating Roads: The heights of the nodes of all triangles, consisting of the road region, are equal to the heights of the points created by drawing perpendicular lines to the centerlines from the nodes.

2.3 Building Modeling

In general, most 3D buildings can be described in terms of polyhedra. That is to say, buildings' boundaries can be represented by a set of planar surfaces. In our approach, the borders of 2D buildings are supposed to be correctly defined in the input 2D map, and every building consists of a cuboid element with a flat roof, although the real roof may be a inclined plane, or a gable one, or a hip one[1][?]. In case of cuboid models, a building is consisted of two boundary surfaces, roof surface and ground surface, with different heights and the side faces (Figure 3(c)). Here, two paprameters, *base elevation* and *roof elevation*, must be determined for modeling a building. *Base elevation* is equal to the lowest z value within all points which are the outside of the building and positioned not far away from the building's boundary polygon. *Roof elevation* is the mode value among z values of all LRF points inside the building. Our approach of modeling buildings consists of the following steps.

Pre-processing includes *closing* and *deleting*. Here, closing is used to close adjoining polylines in the building layer of the 2D map because a building's boundary should be a polygon, and *deleting* is needed to delete both left polylines(or lines) and extremely long-narrow triangles after closing. Digital maps are generally consisted of several blocks, and the processing region may cover multiple blocks (Figure 3(a)). That means some border buildings may not be polygons, such as building B in Figure 3(a) which is consisted of two polylines L_1 and L_2, and needs to be merged. Moreover, many unused lines or polylines or long-narrow triangles (building C), which are usually hiden by normal building's boundaries, are left in the digital maps and must be deleted before modeling.

Calculating Base Elevation: *Base elevation* is calculated by finding the minimum z value of all points outside of the building's boundary and being within a specified distance from the boundary.

Calculating Roof Elevation: *Roof elevation* is obtained by finding all points inside the building's boundary and calculating their mode z value.

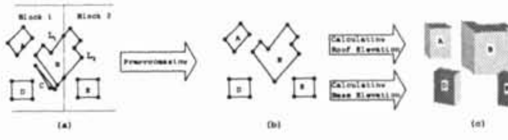

Figure 3: Building Modeling

2.4 Ground Modeling

A ground surface may be obtained from contours. But, it is difficult to acquire the contours for some regions where too many man-made objects exist. If LRF data are dense enough, a ground model may also be carried out by deleting man-made objects from the LRF data and creating TIN with the left points, in the same way as creating a Digital Surface Model(DSM) from LRF data. Here, a dense LRF data may be too costly or impposible for some LRFs. In our approach, we try to use the modeled buildings and roads, obtained in previous sections, and LRF data to model the ground, even though LRF data's density is lower. A TIN-based model of the ground can be obtained through following steps.

Creating TIN from the entire LRF data.

Deleting triangles from the created TIN, if any vertex of the triangle is inside the building's boundaries or road regions.

Filtering triangles by calculating the normal directions of the left triangles and deleting the triangles which are evidently slant.

Modelling Ground by creating TIN again from the undeleted LRF points, with the constraint of building's base boundaries and modeled roads obtained in previous sections.

3 Experiments

The 2D digital map used in our experiment is a TEPCO digital map, with the specifications shown in Table 1, and the input LRF data is acquired by an Airborne Laser Terrain Mappers (ALTM1020, Optech Inc.) at the conditions shown in Table 2.

Table 1: Specifications of the used 2D map

Coordinate	planar rectangular
Scale	1/500
Mesh	400m × 250m
Layers	Buildings, Roads, ...
File type	DXF

Figure 4(a) shows the 2D map, where buildings appear as filled polygons and roads are represented as polylines. Figure 4(b) shows the DSM of the same area, which is created by the measured 3D LRF points

Table 2: Conditions for acquiring LRF data

Aircraft	Cessna 207
Operating altitude	800m or 1000m
Elevation accuracy	15 cm
Horizontal accuracy	1/1000 x altitude
Measurement rate	5000 Hz
Scan angle	10° or 20°
Velocity	180km/h

distributed over the terrain surface and on objects rising from the ground. The identified road regions are shown in Figure 4(c). And the modeled buildings and roads and ground are shown in Figure 4(d). Figure 4(e) is the superimposed result with DSM, indicating their consistency.

4 Conclusion

A new method for city modeling, including roads, buildings, and ground modeling, is proposed in this paper. In the present method, a 2D map is used to locate objects, and a LRF dataset is used to investigate the elevations of objects. Our research shows that using 2D maps leads to the practical utilization of lower-density LRF data. Furthermore, the algorithm for identifying road regions can also be used to convert road boundaries to center lines. The experiment results also illustrate the effectiveness of the proposed method.

As future works, the problems of extending roof models to inclined or gable ones, modeling more objects such as trees, and dealing with highways or overpasses remain to be solved.

Acknowledgments

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References

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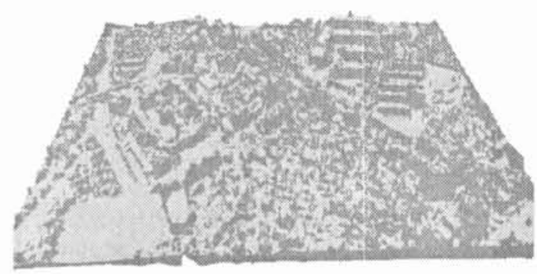
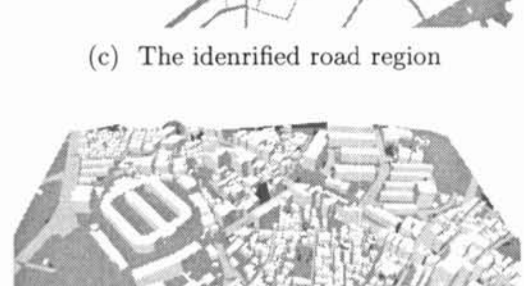
[3] J. R. Shewchuk, "A Two-Dimensional Quality Mesh Generator and Delaunay Triangulator," http://www.cs.cmu.edu/ quake/triangle.html

(a) 2D map: buildings and roads

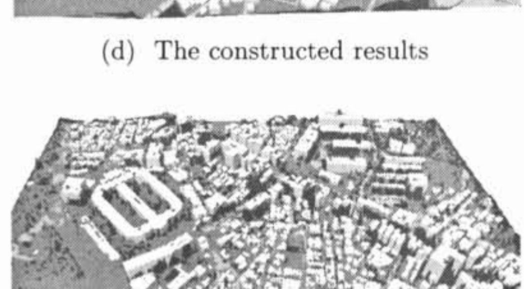


(b) DSM of the LRF data

(c) The idenrified road region



(d) The constructed results



(e) The constructed results with DSM

Figure 4: Experiment Results