HIGHWAY THREE-DIMENSIONAL MODELING BASED ON VEHICLE-BORNE LASER DATA

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Abstract. The of Vehicle-borne LiDAR (Light Detection And Ranging) scanning technology is an efficiently practical approach on the acquisition and application of 3D information and its geographic elements of highway(including road surface, rails, attached facilities, slopes, ditches, etc.). The acquired information is significant on many aspects such as road maintenance, reconstruction, survey, landscape design, visualized modelling and highway hazard supervision and prevention. The initial laser data cannot be directly used to construct highway 3D model, operations of pre-processing are necessary. This paper presented a set of procedure about pre-processing laser data and constructing TIN (Triangle Irregular Net) model of highway.

1. Introduction
3D model of highway is traditionally built with road features extracted from RS (Remote Sensing) images, coordinates measured by GPS or Total Station device and road design data¹-². This method is inefficient and laborious, and the accuracy of data is susceptible to subjective factors. VLMS (Vehicle-borne Laser Measurement System) can obtain spatial coordinates (X, Y, Z), attributes (reflection intensity and RGB values) and images of spatial objects located within the detection range while moving, with advantages of efficiency, abundant information and accuracy. In addition, highway 3D model constructed by laser data is totally up to the demand of measurement job of highway survey and design, highway reconstruction and extension. Obviously the old-fashioned method will be replaced by the higher-tech one.

2. Flow chart
The flow chart of this paper is shown as figure 1.
3. Data pre-processing

3.1. Data preparation
Generally, the density of ground laser points decreases with scanning distance increasing. In addition, laser points on the reverse lane maybe missing due to being blocked by isolation belt. In order to ensure the quality of model, it is better to gather road data bi-directionally, output unilateral data by setting the distance parameter and process each data respectively.

3.2. Filtering
The initial data include road surface, slopes, ditches, fences, isolation belts, vehicles, street lights, billboards, trees, grass, etc. To construct highway 3D model, only points of road surface, slope and ditch are needed. Therefore, filtering process is the first step, and the result is directly related to the quality of model. Furthermore, this step is conducive to extraction of feature coordinates by wiping off influence of ground points.

Currently, there are quite a number of published researches about feature extraction and filtering based on vehicle-borne laser points [31-61]. According to the phenomenon that ground points of scan line are located in bottommost position in local cross-sectional view, and the idea of irregular partition, the researcher designed a integrative method about extraction of ground points (road surface, slope and ditch). The main idea of algorithm is as follows:

I. First of all, the sequence of points in single scan line is ranked by horizontal position, the elevation minimum point (P₀) is supposed to be a ground point.

II. Point P₁ with the minimal elevation among the points left to P₀ (the right side is in the same way) is also supposed to be ground point.

III. If the number of points between point P₀ and P₁ is greater than 0, find out Pₘ with minimum elevation between P₁ and P₀ (figure 2-a), else that P₀=P₁, go to step II. After that, calculate the difference values of slope (computing method of slope (α) is as formula 1) and that of elevation among point P₀, Pₘ and P₁, which are regarded as judgment factors. If these difference values satisfy the predetermined thresholds and conditions, point P₁ is supposed to be ground point, so that P₁=Pₘ, go to step III(figure 2-b), else point P₁ is supposed to be non-ground point, so that P₀=P₁, go to step II (figure 2-c).
3.3. Data repairing
Due to being blocked by passing vehicles, fences, trees and other objects, it looks like that there are some “holes” on surface of ground data which are extracted in previous section. Considering aesthetics and integrity, these holes need to be repaired before constructing TIN, especially those caused by vehicles.

Firstly, a number of relatively complete adjacent scan lines are selected to set up as a sample data set (S), and ready to be checked data line (Li) is next to the last scan line of the data set (S). Next, line (Li) is compared with data set (S) and relevant points are inserted into the data missing position on line (Li) based on certain rules. After checking and repairing, Line (Li) is added to the sample data set (S), at the same time the first line of data set (S) is removed in order to keep the appropriate size of the sample data set (S). To achieve a better result, it is necessary to repeat the repair work more than once.

3.4. Feature coordinate extraction
To create highway landscape model or census road subsidiary facilities, features and their coordinates need to be extracted, such as utility poles, street lights and trees along the road, etc. Utility poles and street lights have unified standards. Trees can be set to be a certain species regardless of reality. Their coordinates can be extracted by a certain rule, so that unified 3D models could be planted into highway 3D model according to coordinates of features.

There are some researches on feature extraction, both domestic and overseas. In the paper, utility poles and street trees are main study objects. First of all, the data of ground points have been filtered off is divided into blocks by regular cube, each block is a study unit. One block is cut into several layers based on a certain height. Next, the density of projected points is calculated in every layer that spatial correlation exist 3D models could be planted into highway 3D model according to coordinates of features.

As a whole, utility poles have their own spatial characteristics that the spatial structure keeps vertical basically, its horizontal projection is concentrated in a small area, and so on. Spatial characteristics of tree trunk are similar to those of utility poles. But spatial characteristics of tree crown are pretty much different. So this is the key point to distinguish trees from poles. Figure 3 shows schematic diagram of tree extraction. After extracting features, position coordinates of features are appointed to be the center of the bottom.

\[
\alpha = \tan^{-1}\left(\frac{Z_i - Z_{i-1}}{\sqrt{(X_i - X_{i-1})^2 + (-Y_{i-1})^2}}\right)
\]

\[
\alpha_i \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right], \ i = 2, \ldots, \ n
\]
4. HIGHWAY MODELING

4.1. Constructing TIN model
Each scan line represents a cross section of highway. And narrow strips sandwiched between adjacent scan lines can splice into the entire highway surface. In addition, constructing TIN based on adjacent scan lines can express details of local areas. Therefore, the author utilizes a triangulation method based on scan line to construct TIN of highway. This method is suitable for constructing model of zonary terrain. The main idea is as follows:

I In line ($L_i$), a couple of adjacent points are treated as two vertices of one triangle. As shown in figure 4-a.

II With regard to the couple of adjacent points, if the included angle, a point on line ($L_{i+1}$) as the vertex of angle, achieve to maximum that the point on line ($L_{i+1}$) is confirmed to be the third vertex to make up a triangle. As shown in figure 4-b.

III If the beginning (or ending) point on line ($L_{i+1}$) has not been assigned, there is no doubt that the beginning (or ending) point on line ($L_{i+1}$) are in same triangles with those on Line ($L_i$). Except for the beginning and ending point, one unassigned point on line ($L_{i+1}$) and the adjacent point in line ($L_i$) are in same triangle. As shown in figure 4-c.

IV Also, a couple of adjacent points on line ($L_{i+1}$) belongs to one triangle, so that three vertices of all triangles between line ($L_{i+1}$) and line ($L_i$) have been confirmed. As shown in figure 4-d.

![Figure 3. Schematic diagram of tree extraction](image1)

![Figure 4. Schematic diagram of triangulation](image2)
4.2. Loading feature model
Unified 3D models of utility poles and trees can be loaded into highway model according to these position coordinates. It is the best way to simulate highway landscape realistically. It is far beyond other methods on constructing highway 3D model can keep up with this method in reality, accuracy and practicability.

5. EXPERIMENT ANALYSIS
The author selects a piece of representative data (figure 5), which contains road surface, slopes, ditches, trees, and vehicles etc. Based on the aforementioned algorithms, automated extraction of ground laser points and TIN construction are achieved. The result of TIN construction is as shown in figure 6.

6. Conclusion
The paper describes a technical process and key methods about building highway 3D model, and does a brief description of the algorithm. In the end of paper, a part of experiment results is displayed. Furthermore, integration of programs and improvement of algorithms will be achieved next. As a new mean of measurement, the technology of vehicle-borne LiDAR will be widely used in road-related projects. And the 3D highway model based on vehicle-borne laser points will play a major role in road survey and design, road landscape simulation, road reconstruction and subsidiary facilities investigation, virtual city, etc. in the future.

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