LANE-ORIENTED 3D DYNAMIC SEGMENTATION METHOD

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Commission VI, WG VI/4

KEY WORDS: Dynamic Segmentation, Lane Ribbon, 3D GIS, VGEs, Lane-oriented, Road Network Model

ABSTRACT:

Dynamic segmentation is a method that facilitates the small areas along a line feature to be referenced without actually breaking the line into pieces. However, the current dynamic segmentation methods are almost developed from 2D roadway centerline network models, and therefore they are unable to support 3D lane-oriented inventory management (e.g. pavement condition, traffic volumes, traffic accidents, moving objects at lane level, etc.). In this paper, a novel lane-oriented 3D dynamic segmentation method, 3DDS for short, is proposed. 3DDS is built on hierarchical, lane-oriented 3D road network model, while the datum is set directly on the 3D lane ribbon and two events description alternatives (semantic-based description and point sequence-based description) are correspondingly developed. The prototype is built on 3D GIS software (VGEGIS 5.0) and the experimental results shows the effectiveness of the 3D lane-oriented geovisualization.

1. INTRODUCTION

Dynamic Segmentation is a two-step process performed on a spatial data set comprised of linear features. By using dynamic segmentation, small areas along a line feature can be referenced without actually breaking the line into pieces. Also, linear distances can then be calculated directly from the routes and associated attributes. Because of its core role in the field of GIS in transportation (GIS-T), the research of dynamic segmentation has gained much attention from both transportation and GIS domain(Goodchild, 2000; Huang, 2003; Miller and Shaw, 2001; Nyerges, 1990; Zhou and Zhang, 2003; Zhu and Li, 2007).

To date, most dynamic segmentation methods were developed from 2D roadway centerline network model. The situation is caused by two main reasons. First, our road digital maps commonly used were almost 2D. Second, the road network was mainly served for macroscopic application such as highway inventory management. With the quick development of 3D data capture techniques and VR technology (Shi, Nakagawa et al., 2004; Wong, Wong et al., 2005), more detailed 3D road network models are available, and consequently, there are natural gaps between current 2D implementation of geovisualization and the needs for 3D microscopic inventory management (e.g. lane-oriented traffic flows and accidents, lane-oriented pavements, etc.).

Besides the underlying 2D road network model, the past research on dynamic segmentation mainly adopted “road name-reference point” linear reference method and “one-dimensional offset” event description method. “Road name-reference point” linear reference method needs a route system which is created by associating adjacent line segments into one or more groups that have a definite linear sequence while one-dimensional descriptive information is associated with the route system by referencing distances from the starting point of each route. Nevertheless, it is difficult to construct every route in a large scale urban network system and the reference point is hardly to choose. Moreover, the “one-dimensional offset” event description method can only support dynamic segmentation for 2D point or linear events. As a result, there are still bottlenecks of using the existing method into 3D lane-oriented microscopic urban transportation applications.

Some researchers have been proposed strategies for updating traditional dynamic segmentation method into 3D microscopic urban transportation application from diverse angles. For example, introducing “link-node” reference method to improve the location accuracy of events(Li and Lin, 2006); using 3D datum to provide 3D reference basis(Zuo, Li et al., 2005); considering lane-based semantic information for the purpose of visualizing area events at the lane level(Malaikrisanachalee and Adams, 2005). However, those methods ignore either lane topology or lane geometry into lane-oriented dynamic segmentation, and the implementation issues are either vague or ambiguous.

In this paper, a novel lane-oriented 3D dynamic segmentation method, 3DDS for short, is proposed. The research of lane-oriented 3D dynamic segmentation method is based on the newly proposed hierarchical, lane-oriented 3D road network model (Zhu and Li, 2007). The remainder of this paper is organized as follows. Section 2 discusses the conceptual model, algorithm flow and three key issues involved in the lane-oriented 3D dynamic segmentation. Section 3 covers the prototype and implementation issues. Finally, concluding remarks are presented in Section 4.

2. LANE-ORIENTED 3D DYNAMIC SEGMENTATION

2.1 Conceptual Model

The general concept of developing a lane-oriented 3D dynamic segmentation method is to provide 3D microscopic geovisualization of events (e.g. pavement condition, traffic

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volumes, traffic accidents and moving objects) at lane level without actually breaking the lane ribbon into pieces or actually storing the lane-related events as 2D polygon or 3D feature.

The conceptual model of lane-oriented 3D dynamic segmentation has been designed by the unified modeling langrage (UML diagram). As shown in Figure 1, there are three parts in the conceptual model, namely cartographic data, linear reference system and event. In each part, several objects are further defined.

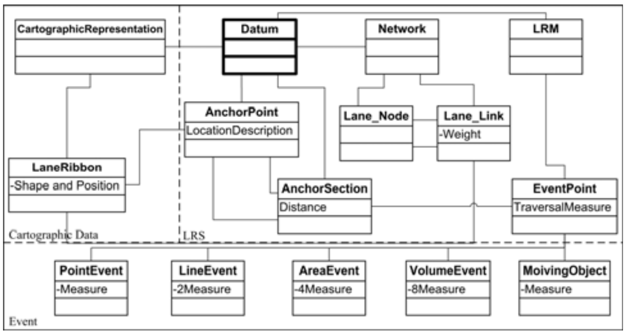


Figure 1. Conceptual Model of the 3DDS

- Cartographic representation: a set of 3D lines or 3D polygons that can be mapped to a linear datum. Cartographic representations provide coordinate references as well as the basis for to-scale visualization of other components of the linear reference system model.
- Datum: Set of quantities that may serve as a reference or basis for the calculation of other quantities.
- Network: the topological object, consisting of an aggregation of nods and edges that forms the basis for operations such as pathfinding and flow.
- Linear reference method: it provides a means of identifying a location by reference to a segment of a linear geographic feature and distance from some point along that segment.
- Event: an instant or period in which something happens that changes the state of an object. Broadly speaking, events include four types: point event, line event, area event and moving object such as vehicle.

Compared with the National Cooperative Highway Research Program (NCHRP) model(Adams, Koncz et al., 2001), 3DDS has some new characteristics. First, it is datum-oriented instead of network-oriented. The multiple geographic representation as well as multiple topological representation have been connected to datum directly, as such the datum are taken as the core role among cartographic representation, network and linear reference method. Second, it uses lane ribbon as the minimum primitive for geographic representation instead of road centerline. Lane ribbon is represented as an elongated region with clear boundaries on a road surface, to allow the representation of the photorealistic geometric configuration of individual lanes. Third, it uses real lane as the minimum primitive for network topologic analysis. The costs of routing will attached on real lane and each real lane are connected to a single lane ribbon for its cartographic representation. Last, it uses three dimensional offsets to locate 3D point, line, area and volume events. The three dimensional offsets cover horizontal, vertical measures relative to geographic position of lane ribbon.

Shortly, the conceptual model of 3DDS overwhelms the traditional one-dimensional dynamic segmentation method in its higher accuracy in geovisualization and more flexibility in lane-oriented event recording. It facilitates inventory management at lane level and wider application in urban transportation network systems.

2.2 Algorithm Flow

In the conceptual model, the key objects have been illustrated and the relationships among the objects have been built. However, in order to transfer the conceptual model into implementation, a reasonable algorithm flow must be given. In the traditional dynamic segmentation method, the algorithm flow can be summarized as four steps: constructing route system; setting datum; inputting event table; interpolating and geovisulizing. As such, an important step is to input sets of lines and manually organize linear route system. Basically, the traditional algorithm flow will be problematic in microscopic urban network because the building of route system is a time-consuming task and the work is far more complicated in lane-oriented network system.

In the 3DDS, the algorithm flow has been re-organized as three steps, namely event-inputting; datum-setting; dynamic-segmenting, as shown in Figure 2.

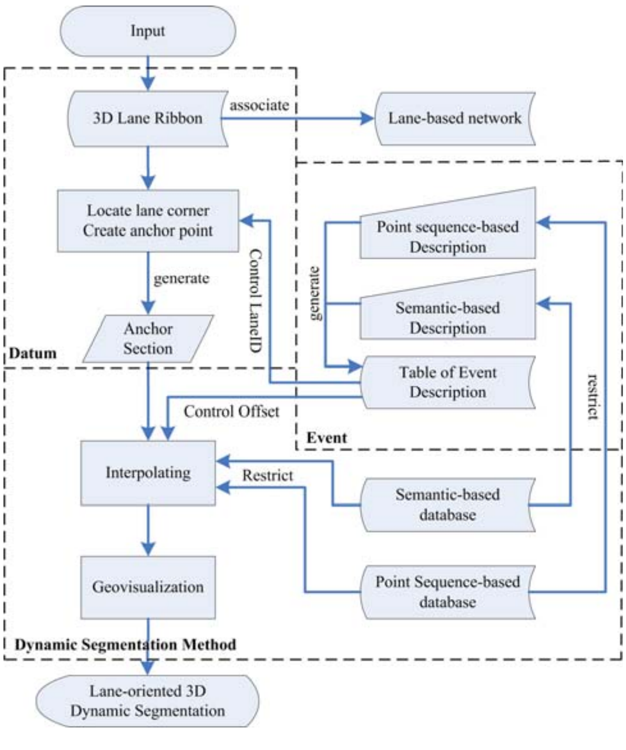


Figure 2. Flowchart of the 3DDS implementation

Step 1: Sets of lane ribbons are loaded into virtual geographic environments, and those lane ribbons are co-related to lane-oriented topologic network, in order to facilitate lane-oriented routing and navigation. Two kinds of event tables are input into the system.

Step 2: The datum-setting process in initiated automatically when event tables are input into scenes. In this step, the program will locate the target lane ribbon by reading the key attributes (LaneID) of the event tables, and similarly a horizontal and linear anchor section are recorded into system.

Step 3: The last step is to dynamic generate 3D graphs of events. In this step, the interpolating methods are adopted by reading the offset value of the event table and sets of interpolating points are collected into system.

It is obvious that the design of the event table is vital to the 3DDS. The key issues involved in the algorithm flow will be further discussed in the next section.

2.3 Three Key issues

- Datum-setting on lane ribbon

As aforementioned, there are several reasons for abandoning 2D roadway centerline-based datum in urban network systems: first, the location of roadway centerline is quite difficult to capture especially in complicate urban network with many irregular lane barrier. Second, more and more transportation applications are now facing complicated 3D road network system, flyovers and tunnels are kinds of examples.

Datum-setting directly on lane ribbon provides a new solution for the above problems. It is because that lane ribbons have clear boundary on the road surface and these kinds of information are more suitable to be gathered with photogrammetry techniques. It also assumes that using the lane corner on each lane ribbon could provide more accurate anchor point for linear, horizontal and vertical reference point. More detailed principles about the datum-setting are discussed as follows (Figure 3):

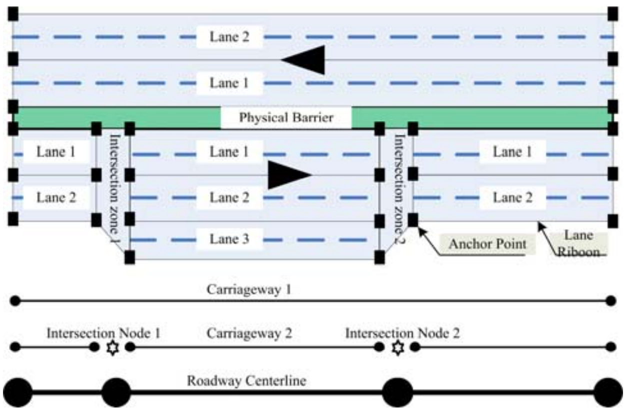


Figure 3. Diagraph of lane-oriented datum-setting

Principle 1: According to the direction of traffic flow, it is favourable to set a group of characteristic points from the lane corner, to be formed as linear and horizontal anchor section. In practice, the sequence of the lane corner can be recorded as the sequence of digitizing the lane ribbon in clockwise direction. Take a four-corner lane ribbon as an example, the corner 1 is set to locate on the lower left on the lane ribbon, while corner 1 and corner 2 represents the characteristic points of linear reference and corner 1 and corner 4 represents the characteristic points of horizontal reference. For more complicated situation where the lane ribbon is constructed by above 4 point corners (N) with change of direction, it is assumes that corner 1 and corner N/2 to be as the linear reference point and corner 1 and corner N to be as the horizontal reference point.

Principle 2: for intersection zone, because of its irregular configuration, it is impossible to use the traditional linear offset method to record the geographic location when events happen to locate at the intersection zone. In such condition, it assumes that the datum can be set directly on the intersection node (I_Node), which is a part of feature in carriageway-based network. By combining the more detailed semantic descriptive information (e.g. left-above, right, lower-right, etc) and the geographic information of intersection zone, the location of events can be well geovisulized.

- Three-dimensional offsets

The commonly used linear reference methods have three kinds of types: road name-reference point method, control section method and link-arc method. Among the methods, the last one is free of constructing a route system beforehand and owns a sound basis for more accurate inventory management, especially for urban road network system.

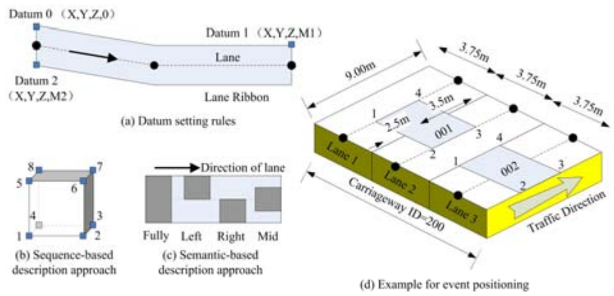
In this paper, the general frameworks of link-arc method are adopted. Based on the framework, a three-dimensional offsets method, namely “link-distance-lane sequence”, is further proposed. Link represents the topologic element inside a hierarchical, 3D lane-oriented road network model; distance represents the linear offset along lane ribbon while lane sequence provides extra horizontal reference on the lane ribbon. In operation, link shows which carriageway the events locate, distance shows how far the events locate from the beginning of the lane ribbon and lane sequence shows which lane and its relative position the events locate at. As such, a three-dimensional offsets transfer the linear measures to 3D coordinates (comparison of linear coordinate to geographic coordinate between traditional method and 3DDS shown as follows).

(RouteID， RPID， Measure_linear) → (X， Y)
(LinkID， Measure_linear， Lane_Sequence) → (X， Y， Z)

- Multiple event description

Based on the three-dimensional offsets linear reference method, two event description methods, namely “point sequence-based” and “semantic-based”, are discussed in this section. The first method uses the event point information (three-dimensional offsets of each event corner) to construct the geovisualization and it can be described as a tuple <linkID, lane sequence, linear offset, horizontal offset, vertical offset>, while the second method uses the semantic information (relative semantic relationship on lane ribbon) and the tuple is <linkID, lane sequence, linear offset, semantic description, elevation>. In the second method, several semantic descriptions can be further defined, such as <Full，left-side， right-side， middle>, which represents the relative horizontal location on the lane ribbon. The parameters of elevation represent the height information of the events.

In Figure 4, datum setting rules and the two dynamic segmentation methods are illustrated. The first step for dynamic segmentation is to automatically select the characteristic point as the reference point, by combining the extra attribute information such as length and width of the lane ribbon. In method 1, two events (event 001 and event 002) are described with the tuple <CarriagewayID, Lane sequence, Relative position, Start position, End position, Elevation>. And the same events can be described in method 2 with the tuple <CarriagewayID, Lane sequence, linear offset, horizontal offset, vertical offset>.



Method 1: Semantic-based event positioning

EventID	CarriagewayID	Lane Sequence	Relative Position	Start Position	End Position	Elevation
001	200	1,2	Left, Right	2.5	6.0	0
002	200	3	Fully	2.5	6.0	0

Method 2: Sequence-based event positioning

EventID	Corner 1					Corner 2					Corner 3					Corner 4				
	C_ID	LS	O1	O2	O3	C_ID	LS	O1	O2	O3	C_ID	LS	O1	O2	O3	C_ID	LS	O1	O2	O3
001	200	1	2.5	1.825	0	200	2	2.5	1.825	0	200	2	6	1.825	0	200	1	6	1.825	0
002	200	3	2.5	3.75	0	200	3	2.5	0	0	200	3	6	0	0	200	1	6	3.75	0

Figure 4. Examples of lane-oriented dynamic segmentation

3. PROTOTYPE AND IMPLEMENTATION

The prototype was built on a 3D GIS software－VGEGIS5.0 developed by Wuhan University. The development and implementation environments are: Intel(R) Pentium(R)4，CPU 2.00GHz 1.99GHz，512MB RAM. The Programming Tool is Visual C++6.0 and Graphical Interfaces is OpenGL. The sample data is a series of main roads, including 3D road segments, 3D carriageways, 3D lane ribbons, and 3D intersection points. There are two basic functions: point sequence-based dynamic segmentation and semantic-based dynamic segmentation. The comparative analysis is done between ARCGIS (ESRI, 1993) and VGEGIS 5.0 to testify the effectiveness of the proposed 3D dynamic segmentation method（Figure 5）.

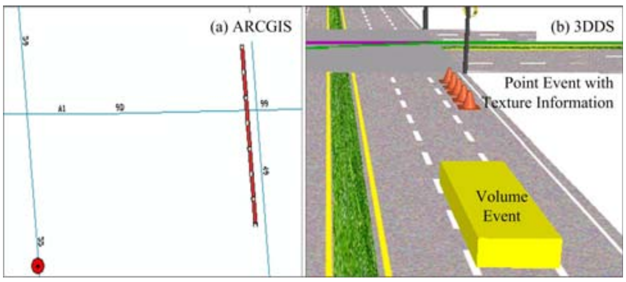


Figure 5. 2D and 3D prototype for dynamic segmentation

The experimental results show that（Table 1）:

1) Compared to traditional dynamic segmentation method, 3DDS provides more accurate lane-oriented event geovisualization; the event type has been expanded to point, linear, area and volume formats.
2) The process of setting datum is automatically, there is no need to pre-define the route system and select reference point, which facilitate the 3DDS into urban transportation application.
3) Two kinds of event description methods are given in 3DDS. The point sequence-based method is more accurate and suitable for the management of moving objects and events with complex shape, while the semantic-based method is more flexible for the management of event with regular shapes.

Method	Event	Cartography	Effect	Flexibility
ArcGIS	Point, Line	Centerline	2D	Highway
3DDS	Point, Line, Area, Volume	Lane Ribbon	3D Texture	Urban Roadway

Table 1. Comparison analysis of 2D and 3D dynamic segmentation

4. CONCLUSION

Lane-oriented 3D dynamic segmentation expands the traditional dynamic segmentation method into 3D microscopic geovisualization at lane level. From the theoretical analysis and experimental results, the effectiveness of 3D inventory management has been testified. It also reveals some potential applications such as virtual object managements in the navigation and location-based services.

While the dynamic segmentation issues have been systematically tackled in this paper, the work can still be extended along several aspects. For example, multi-scale dynamic segmentation and adaptive dynamic segmentation in VGEs when considering the scale effects and diverse needs from users.

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ACKNOWLEDGEMENTS

This research was founded by Xiamen University (Grant No. 0000x071i2)，Wuhan University (Grant No. WKL(07)0301), the National High Technology Research and Development Program of China (2006AA12Z224) and National Natural Science Foundation of China（40671158）. The author would also like to thank Prof. Zhu Qing from Wuhan University for his constant source of help.